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OUTLINES OF BIOLOGY

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BY

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PREFACE

THE formal contents of this book have been determined by the syllabus of the conjoint examining board of the Royal Colleges of Physicians and Surgeons of England, issued for the guidance of candidates preparing for the examination in Elementary Biology. I have endeavoured to set forth the necessary facts plainly, but in such fashion that the relations they bear to each other, and their places in the science of Biology, shall be apparent. The actual facts can be learned only with the microscope and the scalpel. I have tried to make this book serve as a guide in the laboratory, and also to supply the necessary connecting links between the isolated facts presented by the seven or eight plants and animals selected out of the multitude of living organisms. I hope, therefore, that this book may supply outlines of Biology to those who will afterwards proceed to that special branch of Biology, known as the study of medicine, and that it may also serve those who propose to devote themselves afterwards to more detailed study of zoology, with the aid of more advanced text-books.

In following so well-beaten a track, I am indebted to many predecessors, to whom I wish to make grateful acknowledgment. I have drawn all the figures specially for this book ; in two or three cases directly from figures already published, in several cases from the specimens with the aid of published figures. These are acknowledged in their places ; the others are original.

P. CHALMERS MITCHELL

LONDON, 1894.

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OUTLINES OF BIOLOGY

CHAPTER I

PROTOPLASM

LIVING BODIES possess many familiar properties which give them an unmistakable character. We may be unable to distinguish in them growth or movement, the phenomena which we associate most readily with life, but we know that we can produce, by easy mechanical or chemical methods, an arrest or alteration of the processes of life. This arrest or alteration, that we call **death,** we look confidently to be followed by gross changes in the bodily substance. The form and consistency alter : the pleasant neutrality of the odour is replaced by offensive exhalations, and the substance resolves itself into water, ashes, and gases. If we treat the living substance, be it part of a growing root, a green leaf, or part of the fresh tissue of an animal, by strong heat, by placing it in a test-tube held over a flame, first a quantity of water is driven off, and then the substance chars, and there issues a thick smoke in which ammonia and sulphur can be detected. We are thus certain of the presence of hydrogen and oxygen, nitrogen and sulphur, and the charred remains are chiefly carbon, and these elements we shall find to compose the chief elements in living material.

If an exceedingly thin slice or shred of such living material be placed in water or in diluted glycerine, and examined under the microscope, it may be seen to be composed of closely packed, distinct pieces, called **cells**. If the substance chosen is a thin film picked with a needle from the surface of a leaf, or isolated pieces scraped with a blunt edge from the inside of one's own cheek, these cells exhibit definite **cell-walls**, and a central thickening or **nucleus**, and manifestly are separate elements. In most tissues, and especially in the tissues of animals, the outlines of cells are not readily seen. What is more important to notice is that these cells, when taken alive from fresh tissues, and preferably from young growing tissues, are composed of a semi-transparent, greyish material, looking like thin gum into which small transparent granules have been stirred. The substance which has this appearance is **protoplasm**, and is the living part of the cells of all animals and plants. Animals and plants are alive and growing; their protoplasm is alive and growing; and we know protoplasm only as a living substance. Chemical analysis kills it, and dead material is not protoplasm. We know that what we call protoplasm is a mixture, not a single chemical substance. It is alive, and therefore constantly building up food-materials into itself; constantly breaking down part of itself in the process of doing the work of living; constantly, again, forming substances like cell-walls, like enamel, or wax, or horn, which are derived from protoplasm, but are not protoplasm. Thus protoplasm, as we look at it under the microscope, and as we must carry it in our minds, is a flux of chemical materials, some of them food in various stages of the process of building up into living substance, some of them broken-down, waste products from the living material which has been used up,—and some of them substances manufactured by the living material. To see it one chooses young growing cells, for in older cells the living material frequently is obscured by the various substances it has made.

Protoplasm, then, is not a definite chemical compound, but a jelly-like substance one can see with the microscope when one knows where and how to look for it. However, it can be shown that protoplasm consists chiefly of the chemical compounds known as **Proteids**. The general composition of these bodies is—

Oxygen	**from**	**20·9**	**to**	**23·5**	**per cent.**
Hydrogen	„	**6·9**	„	**7·3**	„
Nitrogen	„	**15·2**	„	**17·0**	„
Carbon	„	**51·5**	„	**54·5**	„
Sulphur	„	**0·3**	„	**2·0**	„

Besides Proteids, protoplasm always contains a large bulk of **water**, small quantities of **carbo-hydrates** and **fats**, and traces of **iron** and of **phosphates** and **sulphates** of **potassium**, **calcium**, and **magnesium**. Hence it is probable that, if in the material called protoplasm a special chemical compound be present, the molecules of this chemical compound are much more complex than the molecules of Proteids.

Protoplasm is dissolved by weak acids or alkalies, though in this process of solution it is destroyed, and cannot, like a simple chemical substance in solution, be recovered unaltered by precipitation or evaporation. Strong alcohol coagulates it, but this again changes it as water is withdrawn in the process. Heating it to about 40° Cent. coagulates it just as white of egg, the best-known proteid, is coagulated by boiling. It must be noticed that all these methods kill animals or plants just as they alter the living material of these animals and plants.

But without the aid of chemistry enough may be observed about protoplasm to give it a very definite place in the world of facts. First of all, protoplasm has the power of movement. This can be seen particularly well in the delicate cells which form the hairs of many plants. The staminal filaments of *Tradescantia* (the Virginian spiderwort) are set thickly with delicate blue hairs. A newly-opened flower should be chosen, and one or two of the blue hairs must be removed with great care and placed on a slide in water under a glass cover-slip. The hairs are seen under the microscope to be composed of elongated barrel-shaped cells disposed in single rows. On careful focussing, the inner wall of each cell is seen to be lined with a layer of protoplasm, thin in some regions, heaped up in others (Fig. 1. *a*). In or near the middle of the cell is seen the nucleus, a rounded, more opaque, solid-looking mass. The nucleus is embedded in another irregular mass of protoplasm, and from this to the layer round the cell-wall there pass delicate strands irregularly arranged and often branching and running into each other. In this network of protoplasm may be seen granules of different shapes and sizes ;

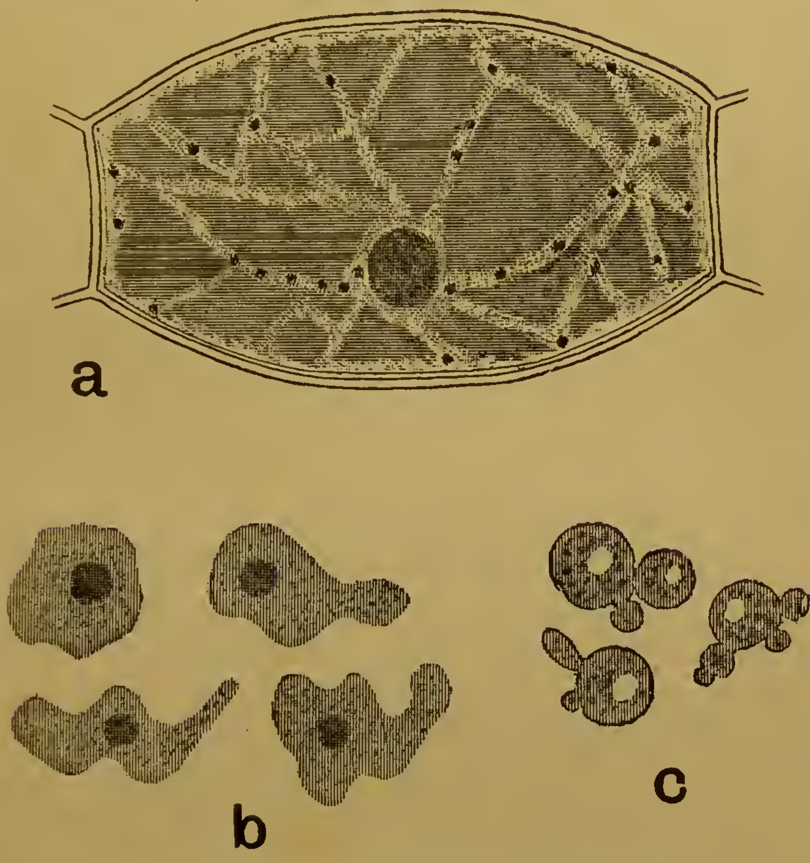


FIG. I.—a. Cell from staminal filament of *Tradescantia*. The protoplasmic threads are light, and in them are contained the nucleus and chlorophyll granules. The spaces between the threads are filled by coloured cell sap.

b. A White or Amœboid Corpuscle from the blood of a frog showing changes of shape undergone during five minutes.

c. Group of Yeast-cells exhibiting active budding.

some are opaque, some readily catch the light if one moves the mirror of the microscope backwards and forwards. When the eye has become accustomed to the semi-transparent protoplasm, it may be seen that constant streaming movements take place, especially in the fine strands running to and from the nucleus. In some of these, the protoplasm and granules are moving towards the nucleus, in others, away from it; while occasionally in the same strand there are two currents passing in opposite directions. In this restless activity the shape and direction of the strands are always changing, some disappear, new ones arise, the cross connections break down and are reformed in new places, and the whole appearance of the network changes from time to time. Living protoplasm moves.

Another kind of movement can be seen in white blood-corpuscles. If a drop of fresh blood, taken from a newt or frog, be placed on a perfectly clean slide and covered by a thin cover-slip, the microscope reveals the presence in it of a number of large oval cells with regular outline and reddish tinge. But among these may be seen a less number of smaller, irregularly shaped, transparent masses of protoplasm. As the preparation would soon dry by evaporation, if unprotected, a film of oil should be drawn with a brush round the edge of the cover-slip. Then, if we watch one of these white or colourless corpuscles, we see that the shape slowly changes (Fig. 1. *b*). At first, most probably, it appears covered with delicate prickles, which are really extensions of the protoplasm of the cell. Sometimes some of these processes lengthen, become thicker, and even may bend on themselves. A group of processes may get pushed out on one side, while those on the other become withdrawn. Moreover the shape of the whole cell is constantly altering, and the cell itself slowly creeps or moves through the liquid in which it is floating, by the extension of processes on one side, and their retraction on the other. Careful focussing shows that, as in the hair-cell of *Tradescantia*, the protoplasm appears to consist of a clearer substance with granules imbedded in it, and both clear substance and the granules share in the streaming movements. In this case, however, the movements, instead of being confined within a motionless cell wall, cause movement through space of the whole cell. This second kind of movement is called **amœboid**, and the processes which are pushed out and withdrawn are named **pseudopodia**. With other forms of protoplasmic movement the student will become familiar, but these two forms may be taken as sufficient to show the fact of movement.

The movements of the protoplasm of *Tradescantia*, or of the white corpuscles, sometimes cannot be seen when the preparation has just been made, whereas after a few minutes they are very visible. The shock of removal to the glass may have arrested their motion, and slight pressure with the point of a needle on the surface of the cover-slip may again produce quiescence, while activity is resumed if the stimulus has been slight enough to do no damage. Gentle warmth stimulates the movements until about 45° Cent. has been reached, when all movement ceases. Electric shocks, and the application of many chemical substances, accelerate the movements. All these show the second striking fact about protoplasm—that it is **irritable**, that it is able to respond to stimuli. Besides the stimuli mentioned, a very little observation of the protoplasm in living animals and plants shows that light, food, variations in the fluids, purity or impurity of the fluids in which the organisms are living, serve as stimuli, increasing or diminishing protoplasmic activity.

Next, protoplasm **absorbs food.** Sometimes, as with animals, the food consists of the bodies of other animals and of plants : sometimes, as in most plants, the food is purely inorganic. The details of the nutrition of protoplasm will have to be considered later on. Protoplasm constantly is exchanging gases with the surrounding air or water ; but the details of the **respiration** or breathing of protoplasm must also be treated at length later. As a result of feeding, protoplasm **grows.** Sometimes, as in the body of an adult, growth is only sufficient to keep pace with the waste of tissue which goes on in all living animals and plants. But in the greatest number of cases growth means actual increase in size. The separate cells, however, do not grow indefinitely large. After a certain size, which is different in different kinds of cells, a cell on the point of overgrowth gives off a bud which grows into another cell, or which directly divides into two daughter cells. If we examine with the microscope some of the white frothy substance from a brewer's vat called yeast, we see that most of the separate round cells which have been floating in the sweet nutritious juices in the vat are actively budding (Fig. 1. *c*). This is the simplest kind of **reproduction,** and in reality is a form of growth.

Finally, protoplasm **excretes,** or turns out waste products. In the processes of life, substances generally coming from broken down protoplasm are extruded by the protoplasm. Many of these substances are soluble in water, and are turned out in a watery fluid. The actual occurrence of this can be seen beautifully in many single-

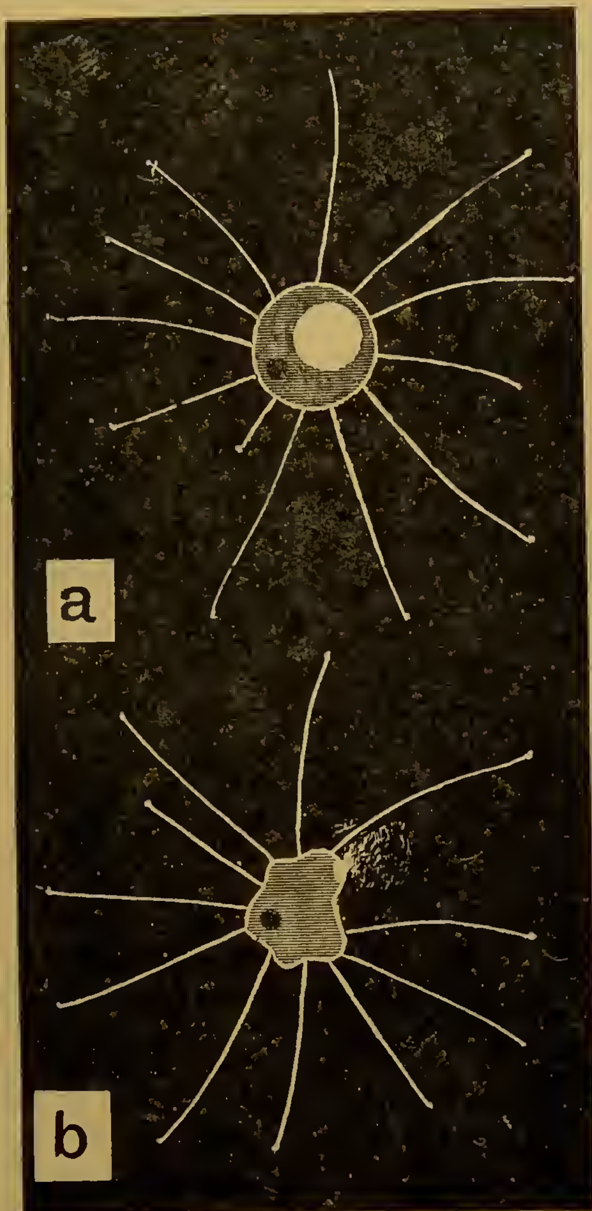


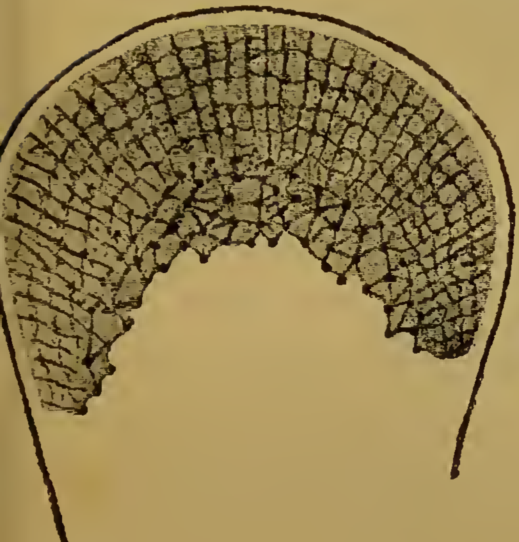
FIG. 2.—**a**. A Single-celled Animal (belonging to the *Acinetans* or suctorial *Protozoa*) with delicate spherical cell-wall, and long knobbed pseudopodia; within the protoplasm lies a small nucleus and a large contractile vacuole.

b. The same; the contractile vacuole has disappeared, the contents being extruded: the shrivelling of the cell-wall shows the loss of bulk undergone.

celled animals. If one takes some pond or ditch water and examines it under a microscope, many small animals and plants may be seen. But if it be poured overnight into a flat pan in which two or three clean glass slides have been placed, a number of single-celled organisms will settle down on the slides during the night. If these slides be lifted out carefully, wiped on the under surface and covered with a cover-slip, one can hardly miss finding a minute single-celled animal, from the spherical wall of which there radiate out a number of slender knobbed pseudopodia. The protoplasm is clear and granular: there is a small nucleus : but most obvious is a round spot that looks empty, and that has a diameter at least half the diameter of the whole animal (Fig. 2 *a*). As one looks at it, it suddenly disappears ; the round disc of the cell becomes shrivelled, and in the water a little whirlpool is seen as if an oily liquid had been squeezed out (Fig. 2 *b*). Slowly the spot reappears, gets larger and larger, and bursts again, and in a few minutes it may be seen to fill and empty several times. This spot is called a **contractile vacuole**, and a contractile vacuole is the most visible form of protoplasmic excretion. In most cells the process of excretion goes on slowly throughout the cell, and no special vacuole is seen. But it may be taken for granted that excretion, whether visible or not, goes on in all protoplasm. One must not confound it with the extrusion of solid indigestible particles—a process which can be seen in some living cells—especially animal cells.

Protoplasm, then, is the living, semi-opaque, jelly-like substance composing the bulk of the living cells of animals and plants. It is made up chiefly of water and of the chemical substances known as proteids, and it possesses the properties of—**Movement, Irritability, Feeding, Respiration, Growth** and **Reproduction, Excretion.**

Under high magnification it may be seen that many of the granules appear like the crossing points of a fine mesh-work, and that protoplasm apparently consists of



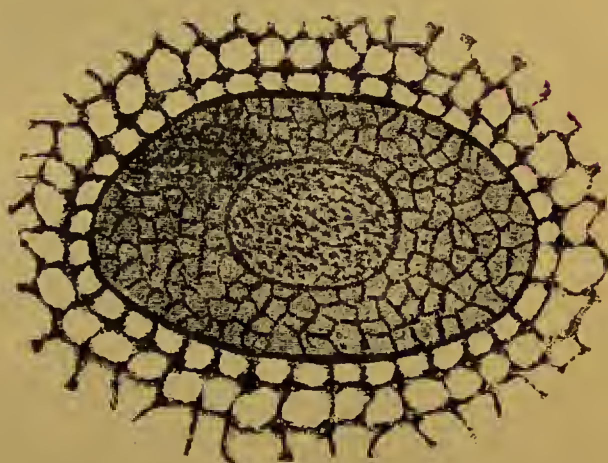


FIG. 3.—Protoplasm of *Amœba actinophora*.
FIG. 4.—Protoplasm of nucleus with part of surrounding protoplasm from ganglion cell of an ox. (From Bütschli.)

a firmer mesh-work, the strands of which are refractive, and a fluid which fills the interstices of the mesh-work (Figs. 3 and 4). Professor Bütschli has shown recently that an artificially produced very fine froth or foam exhibits under the microscope precisely the same appearance (Fig. 5). In his artificial foams the minute bubbles consisted of tiny drops of a kind of soap in solution, each surrounded by a thin film of oil. When a drop of this foam is brought in contact with water, streaming movements, closely resembling the movements in protoplasm, are produced and the drop of foam moves slowly

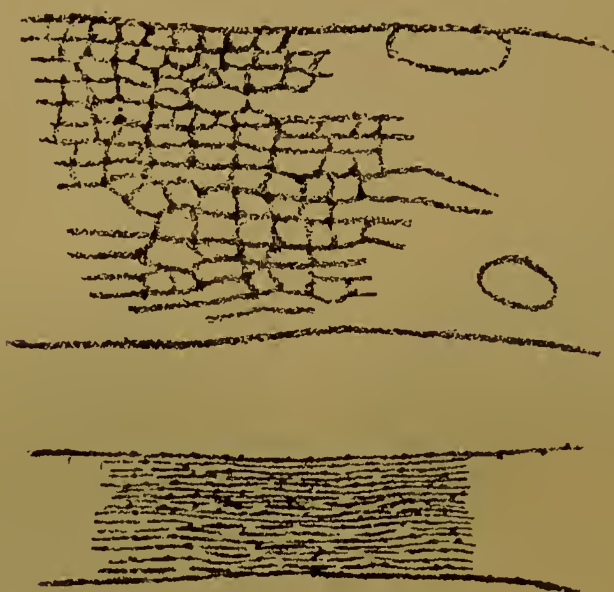


FIG. 5.—Foam of Olive Oil and Carbonate of Potassium, very viscous, much magnified and pressed into fibrils by the cover-slip. The upper figure is a higher magnification of part of the lower figure. (From Bütschli.)

through the water. It is therefore quite possible that the network of protoplasm really is a fine froth, the strands being a fluid surrounding droplets of another fluid—the apparently more liquid part of protoplasm.

CHAPTER II

THE BUILDING UP OF PROTOPLASM

PROTOPLASM and substances formed by it are the material of the tissues of all animals and plants; and all animals and plants, in consequence of this, have the powers of **Movement, Irritability, Feeding, Respiration, Growth** and **Reproduction,** and **Excretion.** The individual cells of the animal or plant bodies may be built up into complicated tissues and organs which serve special purposes, and in the elaborate systems of higher animals and plants these tissues and organs may assist, or regulate, or interfere with each other's work. But, in every case, the actual work done is done by individual cells, and the result that we see is the combined work of the large number of individual cells present in the organs. For instance, the hands may take food to the mouth, the teeth chew it, the muscles of the tongue and mouth and gullet force it down; but it is ultimately the individual cells lining the intestines that absorb and really eat the meal. Similarly all the powers of animals or plants can be traced down to individual cells, down to protoplasm itself.

Practically, then, the living world is protoplasm. In the processes of life, protoplasm is constantly being used up. A starved organism loses in weight, and even while food is abundant, protoplasm is constantly being broken down. When an animal or plant dies and decays, protoplasm is destroyed. How, then, is this substance built up from the inorganic materials in the world?

If we consider the food-supply of the land, it is clear that flesh-eating animals practically only turn the protoplasm of their prey into their own protoplasm, and that their life is dependent on the life of other animals. Animals with an omnivorous diet live partly on animal protoplasm, partly on the tissues of plants. Other animals live entirely on plants. If, seeking an answer to our problem, we turn to plants, we can dismiss many which, like moulds and fungi, live on living or decaying organic matter, and we are left with the green vegetation of the earth. The food supply of the sea is less easy to understand. The vast majority of marine animals are predatory. Most seabirds are fish-eaters; most fish live on other fish, or on small swimming animals like the larvæ of crustacea which abound in the waters. Others live on the shellfish of the bottom, or on worms and anemones and coral polyps. Most of these lower forms of life are themselves carnivorous, and at first sight it seems as if there was no answer to our problem. The amount of floating seaweed or the seaweed round the coasts is not nearly enough to replace the vegetation of the land. Some *débris* comes down from the land; the sewage in the Thames, for instance, ultimately supplies food for the rich fishing stations off Yarmouth or on the Dogger bank; the sewage of the Clyde fattens the herrings of Loch Fyne. But the greater part of the open sea is not supplied with organic remains from the land. If, however, we examine a bucket of surface water there are to be found in it innumerable microscopic plants, and these, like the green vegetation of the earth, form the first stage in the building up of protoplasm ; and like most plants with which we are familiar, very many of these minute plants have a green colour. The starting-point of the food supply of land and sea is green vegetation. The formation of protoplasm from inorganic materials depends on the substance to which this green colouring is due, and which is called **Chlorophyll** (green of leaf). If some green leaves are soaked in alcohol, the green colouring matter is dissolved and forms a clear solution, bright green in colour. This solution is *fluorescent*, for it is green when the light shines through it, but the colour appears red under a strong reflected light.

When examined under the spectroscope it is seen to remove part of the red, but the whole of the blue and violet rays. There probably is a connection between this large absorption of radiant energy and the striking functions of chlorophyll. Every living cell containing chlorophyll in the presence of sunlight performs chemical work. It absorbs carbonic acid from the air, tears apart the carbon and oxygen, and the oxygen is returned to the air. The carbon is not retained as pure carbon, but, probably in the act of being separated from the carbonic acid, is associated with hydrogen and oxygen in the form of a simple carbohydrate—that is, a compound of carbon, hydrogen, and oxygen, in which the hydrogen and oxygen are in the same proportion as they are in water $[C^x(H_2O)^y]$.

This leads to another striking fact. Carbon combines readily with oxygen, and in the process sets free energy in the form of heat. What then takes place in plants, by the agency of chlorophyll, is a turning of radiant energy of sunlight into potential energy; the radiant energy is stored up in the form of a chemical compound of such a kind that, by union with free oxygen, it will liberate the energy again.

From one point of view plants and animals, or the protoplasm of which they consist, may be regarded as centres of force, as things capable of doing work; and here, as the secret of their food-supply, as the first stage in the building up of protoplasm, is to be found a supply of energy, a means by which the radiant energy of sunlight is stored up in a form which can be used. The plants which possess chlorophyll store up the energy: the animals which feed upon plants use this store for their own lives, but retain enough in their own bodies to serve for the carnivorous animals which eat them. Carbon or Carbohydrates, when supplied with oxygen, form carbonic acid, and give out energy as heat. Although the chemical details of the processes of life—what is called the **metabolism** of protoplasm—are very complicated, it may be said generally that protoplasm takes in oxygen, performs the work of life, and gives out carbonic acid; and that it is enabled to do this by the capacity chlorophyll has for absorbing the energy of sunlight and storing it up in the form of carbon compounds with less oxygen than the proportion in carbonic acid (CO_2).

CHAPTER III

GREEN PLANTS

Protococcus[1] AND *Spirogyra*

THE bark of trees and the surfaces of palings are frequently covered by a green layer, which comes off as a green powder if the finger or the sleeve of one's coat

[1] The name *Protococcus* has been applied both to the resting and to the motile phases of two plants:

Pleurococcus vulgaris.

Synonyms—*Protococcus vulgaris.*
Protococcus communis
Hæmatococcus vulgaris.

This is the green alga occurring abundantly on the bark of trees, old palings, &c. It has a resting and a gonidial phase; the latter, when in water, is ciliated, and both red and green colour may occur in the same plant, streaked or aggregated.

Protococcus pluvialis, Kutz. = *Chlamydococcus pluvialis*, Br.

This is a very variable plant occurring in water, and having a motile generation usually succeeded by an indefinite number of quiescent forms. It is usually relegated to the *Volvocineæ.*

The quiescent stage obtained from bark, &c., is *Pleurococcus*; that from water is *Protococcus*: the motile stages in water may belong to either.

be rubbed against it. Shake a very small quantity of this green powder on a glass slide ; cover with a drop of water and a glass cover-slip, and examine under a higher power of the microscope. The powder will appear as a number of cells with green-coloured contents, occurring sometimes solitarily, but more often in groups of two, four, or more (Fig. 6 *a* and *b*). This occurrence in groups is due to division ; the plant has been feeding and growing actively, and division of a cell into two, and of each of the two into another two, is in active progress. The daughter cells gradually become rounded and separate from each other, and various stages in this process may be observed. Select a single large cell for special examination. The cell is surrounded by a definite transparent cell-wall, sufficiently thick to show a double contour. The green contents of the cell are not perfectly uniform, but the green colouring matter (chlorophyll) is confined to a number of small, irregular bodies, named **chromatophores**. These are tightly packed together, and fill up the greater part of the cell ; but here and there, especially in the centre and round the circumference, the clear transparent cell-protoplasm, in which

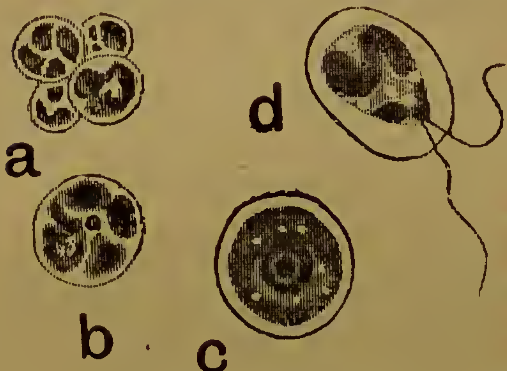


FIG. 6.—**a.** and **b.** *Pleurococcus*. **a.** Four cells in the natural condition much enlarged. **b.** Single cell stained to show the nucleus in the centre surrounded by the chromatophores which are separated from the cell-wall by a short space. **c.** Resting Stage, **d.** Motile Stage of *Protococcus*, showing pyrenoids as white spots.

they are embedded, may be observed. If a few drops of iodine solution be run under the cover-slip, the chromatophores and the protoplasm become more distinct, and, in the clear central space, the nucleus, a small, semi-opaque body almost invisible before, becomes apparent. The cell-wall, like the nucleus and protoplasm, is tinged pale brown by the iodine. If some cells be allowed to soak in strong iodine solution for a few minutes, and then be transferred to sulphuric acid (75 per cent. solution), the brown of the wall turns to a dark blue. This is a characteristic test for a substance closely allied to starch and sugar, called cellulose, which forms the cell-wall of most plant cells.

When these green cells are kept in rain-water, exposed to light, for some days, they give rise to a motile form. Drops of the water, taken from time to time, should be examined under a cover-slip with the higher power of the microscope until small green cells, actively moving about, are observed. In these the cell-wall is thinner, and the chromatophores, compared with the colourless protoplasm, have a smaller bulk than in the resting phase. The cells are slightly elongate, and move with the same end forwards. At this end a pair of delicate processes, nearly invisible until the cell has been killed and stained by iodine, protrude from the protoplasm through the cell-wall. They are termed cilia, and it is by their rapid twisting vibrations that the cell is screwed or pulled through the water.

In the mud from a rain-gutter, or in the semi-liquid scum from a rain-water tank exposed to air, a similar plant, also commonly called *Protococcus*, is abundant. Some of this mud or scum should be mixed with a small quantity of water, and drops of the fluid examined in the same manner as the green powder from the bark. Among the many small organisms present, there may be a number of isolated round cells, coloured green or brown, and possessing a thick cellulose cell-wall (Fig. 6, *c*). The contents consist of protoplasm, chromatophores, and a nucleus, and the cells are the resting stages of *Protococcus*. The colour of the chromatophores usually is green, and is due to chlorophyll ; but it may also be red, or green streaked with red. The red colour is due to a modification of chlorophyll called **hæmatochrome** ; but apparently the use of the material, whether red or green, is identical. Embedded in the chromatophores are numerous small ovoid bodies, which catch the light sharply if the mirror under the microscope be flashed to and fro. When the plant is treated with iodine, these bodies stain a dark blue. They have been found to consist of a proteid substance, covered by a thin layer of starch, and are called **pyrenoids**. They do not occur in the green plant obtained from the bark of trees.

Occasionally the resting stage may be seen to be dividing within the cell-wall. The contents of the cell break up into two, and then into four, and then the cell-wall breaks, and the results of division emerge as tiny elongate cells, which move actively about. But if the actual process of division be not seen in the water containing the resting forms, resulting motile forms are certain to be noticed (Fig. 6. *d*). These move steadily through the water, with one end directed forwards. In the active condition, the chief difference from the resting condition appears to be that the cell-wall is very thin, and is some distance from the coloured contents. But if a drop of solution of iodine be added to the water, movement becomes slower and finally ceases. The cause of the movement can be seen in two long thin colourless threads, each larger than the length of the cell. These "**flagella**," or "**cilia**," project from the cell contents at one end, cross the interval between the cell contents and the cell-wall, and project through that, and by their waving vibrations pull the animal through the water. However long *Protococcus*, in any of its forms, be watched, it is never seen to take in or to pass out any solid particles. The firm structure of the cell-wall would render this impossible. It must live on substances either in a state of solution in water or in a gaseous condition. Either directly from the air or from the rain-water, in which a certain quantity of air is always dissolved, *Protococcus* has access to oxygen, carbonic acid, and nitrogen. The rain-water in which the motile phases live, or the damp situations where resting phases occur, contain nitrates, ammonia, frequently common salt, and small quantities of sulphates and phosphates—chiefly of lime. Thus all the materials for protoplasm are present; and as *Protococcus* grows and multiplies, it has the power of building up protoplasm from them. When a quantity of *Protococcus* is exposed to sunlight in, for instance, a very slender test-tube filled with water and inverted in a saucer of water, bubbles of gas are given off; and when a sufficient quantity has been collected, the gas may be proved to be oxygen. This oxygen comes from the carbon dioxide of the air decomposed by the sunlight and chlorophyll. The stages in the combination of the carbon into proteids and protoplasm are matters of theory. Many simple compounds of carbon, hydrogen, nitrogen, and oxygen occur in plants, and these may be stages in the elaboration of protoplasm. But protoplasm *is* formed, for *Protococcus* grows. It is not even certain where the nitrogen comes from. In the majority of plants the nitrogen of the air is not made use of directly, but is obtained only from salts—chiefly nitrates. Some plants —and among them some green single-celled plants like *Protococcus*—do make use of free nitrogen.

It is by the breaking down of protoplasm that energy, absorbed from sunlight through the agency of chlorophyll, is liberated for the vital processes of the plant. And so there are to be found in cells like *Protococcus* various substances derived from protoplasm, but with a simpler structure. Some of these are clearly useful. The cellulose cell-wall is very indestructible, and protects the delicate protoplasm and gives it some rigidity. The pyrenoids may serve as a store of nutriment. When the plants are in darkness, they are unable to decompose carbonic acid, and—certainly in the case of higher plants —starch, formed in sunlight, disappears in darkness. There are also nitrogen-containing substances formed by protoplasm, and these substances appear to be harmful if retained within it. Where a pulsating vacuole exists, it serves for their removal in a state of solution in water. In other cases they pass out through the cell-wall, or are stored up as concretions.

Without attempting to go into obscure and disputed details, one may lay down that oxygen is used in these changes of protoplasm, and that more oxygen is combined with the substances formed by protoplasm than with the substances of which protoplasm consists. In other words, the processes of life take place by an oxidisation of protoplasm. The oxidised substances are the ashes of the furnace; some of them, because they choke the fire, must be removed; some may be turned to account, as, for instance, to strengthen the walls of the furnace; others—those which are not completely burnt up—may be stored to use when fuel is difficult to obtain. The removal of purely waste substances from protoplasm is called "excretion"; the formation of useful substances is called "secretion"; but these two grade into each other, and probably all secretions were at first excretions. Among the chief excretions of protoplasm are water and carbonic acid. In the case of green plants, the protoplasmic excretion of carbonic acid and absorption of oxygen during sunlight is disguised by the greater activity of chlorophyll—using up carbonic acid and discharging oxygen.

Many other green plants live under conditions similar to those of *Protococcus*. In summer, ponds and lakes and fresh-water streams gradually become fuller and fuller of them. In fresh water which is moderately clear, among the floating green weeds one may pick up handfuls of green threads, which feel silky and slippery. Among these green threads it is easy to pick out with the microscope the plant known as *Spirogyra*. For that plant has the chlorophyll, to which the colour is due, arranged in spiral bands wound round and round within the colourless thread. The thread consists of a number of cylindrical cells of different lengths, arranged end to end (Fig. 7, *a* and *b*). The threads never branch, and the diameter is constant along the thread. Except for difference in the length of the cells, the thread, whether long or short, has the same appearance throughout its length. The threads are unattached and motionless, forming floating masses in water. The cell-walls are colourless and transparent, and a common wall separates cells lying next each other in the threads.

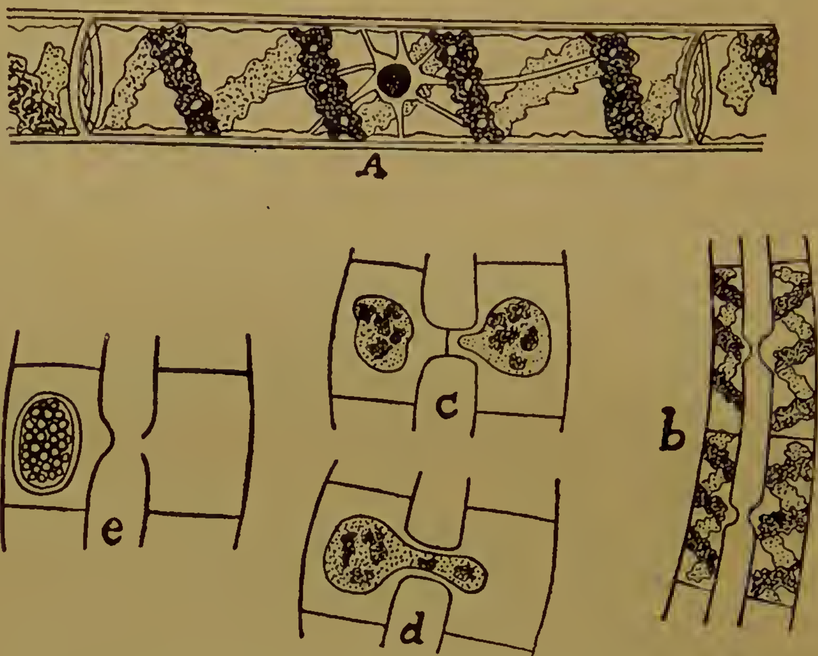


FIG. 7.—*Spirogyra*. **a**. Part of a filament highly magnified showing a single cell with the ends of adjoining cells. The cell-wall is lined by a thin colourless layer of protoplasm from which threads run to the protoplasm surrounding the nucleus and to the chromatophore, which is a green band wound round the interior of the cell and containing pyrenoids.

b, **c**, **d**, **e**. Stages in conjugation. **b**. Adjoining filaments with processes growing out from opposite cells; **c**, **d**, **e**. Two cells in which the chromatophores have broken up and the protoplasm has aggregated into lumps; at **c** and **d** the protoplasm of one cell is passing into that of the other; at **e** the protoplasm of both cells has fused to form a spore in one of them.

The spiral bands vary in number, and in the tightness of the coils, in different species. They are similar to the green masses in *Protococcus* and like them are **chromato-**

phores—masses of protoplasm impregnated by chlorophyll. Embedded in the chromatophores are a varying number of clear bodies like crystals consisting of a central proteid substance covered by a layer of small starch grains, the **pyrenoids.** In cells where the green coils are loosely arranged so that they do not obscure the rest of the cell, streaming **threads of granular protoplasm** may be seen, as in *Tradescantia*, passing from a central body of protoplasm containing a **nucleus,** to a thin layer lining the cell walls. Other streaming threads pass from the nucleus to the chromatophores. Treatment with re-agents is necessary to complete the examination. If solution of iodine be run into the water under the cover-slip, the starch grains surrounding the pyrenoids are stained blue; the protoplasmic threads and the nucleus become tinged with brown. Iodine and sulphuric acid, by tinging the cell-wall blue, show that, as in *Protococcus* and in most vegetable cells, it is composed of **cellulose.**

Very often the protoplasm lining the cell-wall is invisible, while the cell is alive. If a ten-per-cent solution of common salt be run under the cover-slip, water is absorbed from the cell contents, and the protoplasm shrinks, leaving a clear space between itself and the cell-wall.

Protoplasm is so colourless that it is not seen readily under the microscope. It contains many substances which are different in their functions but which, at least in the living cell, cannot be distinguished. For these reasons, elaborate methods of **staining** are required for microscopical investigation. The methods are complicated and very numerous, but they depend on the fact that the different substances, however alike in appearance, have physical or chemical differences which cause a difference in the kind or amount of colouring which is absorbed from stains. A great part of microscopical work consists in the careful selection and application of stains, to pick out the slightest differences in the protoplasm. But simple methods will show much. If some *Spirogyra* be placed for twelve hours in a saturated solution of picric acid, the protoplasm is killed and hardened ("*fixed*" is the technical term), and the chlorophyll is dissolved out. The threads, or small pieces of them, should then be washed thoroughly in distilled water to remove the acid, which has done its work. The threads will now readily be coloured red by a solution of borax carmine. When they have been soaked for nearly an hour in that, they should be placed for a few seconds in alcohol slightly acidified by hydrochloric acid. The acid-alcohol appears to dissolve out the greater part of the stain, but it has a stronger action upon some parts of the protoplasm than upon others. The acid-alcohol must be washed out with neutral alcohol and pieces of the stained plant may be examined on a slide in a drop of glycerine, covered by a slip. But it is better to place a small piece in alcohol on a slide ; to soak up most of the alcohol with the edge of a piece of blotting paper ; to replace it by stronger alcohol ; and after a few minutes soaking to replace by absolute alcohol ; after a similar interval to replace by oil of cloves or chloroform : and finally to replace by canada-balsam dissolved in benzine or chloroform. A cover-slip having been placed on the balsam while it is still liquid, the benzine or chloroform slowly evaporates and a permanent transparent preparation has been made.

In such a preparation the protoplasm is tinged pink. It can be seen to consist of a layer lining the cell-wall and connected by strands with a central mass of protoplasm. This again is connected by strands with the spiral protoplasmic bands, which, impregnated during life with chlorophyll, composed the chromatophores. The proteid part of the pyrenoids is stained darker red, and the nucleus also is stained more darkly than the rest of the protoplasm. In a young cell the protoplasmic layers and strands are larger relatively to the size of the cell, than in an older cell. The cell, in fact, seems to be filled with protoplasm in which there are irregularly placed cavities. In the living condition the cavities are filled with cell-sap, a watery solution frequently coloured, and containing sugar and various soluble bodies. As the cell grows older the cavities or vacuoles increase in size, and the strands and outer layer become thinner and thinner until the adult condition is reached. In that condition the thin layer of protoplasm lining the wall is called the **primordial utricle.**

In the stained specimen it may be seen that the nucleus is a biconcave disc so placed that the faces of the disc are parallel with the ends of the cell. The shape of the nucleus varies in the cells of different plants or animals, in different kinds of cells in the same organism, and even in the same cells at different times. Within the nucleus, darkly stained particles are visible; frequently there is one larger than the other, called the **nucleolus.** The presence within the nucleus of a substance which stains more deeply than the protoplasm is invariable in plants and animals, and this substance from its greater capacity for absorbing stains is named **chro-**

matin. The chromatin may be arranged as a coiled band, in nodules, or in particles so fine as to elude observation. During the division of cells, definite and striking changes occur in the arrangement of the chromatin, and there is strong reason for believing that this substance is the seat of many important properties of cells, and especially those properties that give cells their individual features. If, for instance, the chromatin of two kinds of *Spirogyra* could be interchanged, it is very probable that those differences by which we distinguish the kinds of *Spirogyra* would also be interchanged. As we shall see later, the chromatin is concerned specially in sexual reproduction, in which process cells from two parents combine to form a new individual.

By day, *Spirogyra* like *Protococcus* rapidly assimilates food, and at night, if the temperature is not too low for vital processes to go on actively, the starch grains formed by day disappear, and an exceedingly active growth of protoplasm takes place. When cells have reached their maximum limit of size they divide. By artificially keeping the temperature low at night, this change may be retarded until morning, and may thus conveniently be studied. First, the nucleus divides, going through a complicated process known as Karyokinesis (see Chapter XI), and the two daughter-nuclei withdraw from each other towards opposite ends of the cell. Then the protoplasm of the cell, with the chromatophores, divides in two, and in the middle of the cell a new cell-wall gradually grows in all round the cylinder, finally completing itself at the centre and separating the two halves of the protoplasm and the two daughter-nuclei, so that there are two cells in place of the original cell. In the nuclear division the chromatin first broke up into small pieces, and these pieces each divided, a half passing to each daughter nucleus, so that a very fair division takes place between the two cells, and no distinction can be drawn between them—as, for instance, of mother-cell and daughter-cell.

All the cells in the thread are capable of division, and so the thread may become very long. But, however many cells it may contain, the cells remain alike. The growth of all animals and plants which consist of more than one cell takes place by cell multiplication. In adult tissues the multiplication for the most part is, as in *Spirogyra*, a division into daughter-cells exactly like the dividing cell.

Cell-growth and **cell-division**, then, take place when conditions are favourable; when daylight is long and the assimilation of food rapid, and when the nights are not too cold, and the ponds and lakes rapidly fill with the green weed. But when the heat is too great so that the water is evaporating, or when food is insufficient, in fact, when conditions are unfavourable, another process takes place. In a mass of *Spirogyra*, under such unfavourable conditions, one may feel that some of the threads are tangled and gritty. Under the microscope it may be seen that here and there, in the tangled mass, connections between the cells in different threads exist. A little search reveals various stages in the formation and result of these connections (Fig. 7. *b*, *c*, *d*, *e*). In threads lying parallel to each other, opposite cells send out blunt rounded processes of protoplasm covered by the cell-wall towards each other (Fig. 7. *b*). The whole of the protoplasm in each cell shrinks from the cell-wall and becomes rounded (Fig. 7. *c*). The two processes meet, the piece of cell-wall between them disappears, and the protoplasm from the cell that becomes round more rapidly leaves its own cell, creeps down the connecting-tube and fuses with the protoplasm of the other cell. The nuclei and the protoplasms completely fuse. The new mass of protoplasm remains rounded; a very thick stratified cell-wall forms, and the resulting body is a resting **zygote** or **zygospore**. The wall is composed of three layers, of which the inner can resist water. The starch in the protoplasm is absorbed, and oil globules slowly appear in the protoplasm. It can resist the action of untoward influences much longer than the cells of the plant. The thick wall protects it against drought or cold, and it is this form that survives through winter. In spring, or in favourable conditions, the outer coats rupture, and the protoplasm, protected by the inner layer, grows into a *Spirogyra* thread of the ordinary vegetative kind.

This union of the protoplasm of two cells under unfavourable conditions is called **conjugation**, and it is a process of frequent occurrence among unicellular plants and animals. At first sight the utility of the process seems to consist in the union of the forces of the two cells, to resist the drought or cold, or starvation period. But another consequence of far-reaching importance follows. The resting-spore, or cell resulting from the union of the two cells, unites the slightly varying experiences of the two cells. If there were a method of rejecting the worse half of each cell and forming the new cell from the better halves it would result that the new cell would be an improvement on either of its predecessors. There is no sufficient reason to suppose that this happens; but before the nuclei of the conjugating cells fuse, a part of the chromatin of each nucleus is turned out, and only the remainders actually fuse. If, as is probably true, the chromatin is the bearer or carrier of the chief tendencies of the cell, it is clear that the nucleus of the new cell contains tendencies coming from both conjugating cells. Among the multitude of threads growing out from resting spores formed by conjugation, even if the parts of chromatin selected and rejected were selected and rejected by chance, a very large number of different combinations would result. In the subsequent struggle for life the most suitable combinations would succeed best; the least suitable would perish soonest. And so conjugation may be a method of securing **variation**, and by competition among the varying forms it may lead to gradual improvement or alteration in the organisms.

There is yet another method of interest connected with conjugation. In many cases the conjugating cells are absolutely alike. In *Spirogyra* the protoplasm of one cell remains stationary within the cell-wall; the protoplasm of the other cell, leaving its own wall, bodily migrates into the first cell. In some plants and in many animals, the migrating-cell, instead of merely passing down a short tube from cell to cell, wanders away from its place of origin until it finds, perhaps at some distance, a cell which is ready for conjugation. **Sexual reproduction** in higher plants and animals is really a conjugation of this kind. The motionless cells are the **egg-cells** or **ova**, and usually they remain quiescent within the tissues of the female which gave rise to them; the motile cells are the **spermatozoa**, which, after they have left the male, have to reach and conjugate with the ova. Exactly as in the conjugation of simple forms of life like *Spirogyra*, the new individual formed by the combined ovum and spermatozoon shares characters coming from both parents ; and exactly as in *Spirogyra*, before conjugation takes place, part of the chromatin is ejected by the ovum and spermatozoon.

Spirogyra, then, is a simple plant, living like Protococcus on inorganic substances, and building these substances into protoplasm by a complicated process in which chlorophyll and sunlight take a chief share. Unlike Protococcus, the cells resulting from vegetative division, although all alike, remain attached to each other. But it has, in addition, the process of conjugation, which foreshadows the sexual reproduction of higher organisms.

CHAPTER IV

HIGHER PLANTS

A MINUTE green plant called *Botrydium* (Fig. 8) is not uncommon on moist mud in ditches. As it is one or two millimetres in breadth it is quite visible to the naked eye, and consists of a green bladder-like part above the mud, joined by a narrow neck to a few short branched threads sticking in the mud. Under the microscope, one sees that it is not broken up into cells, but consists of protoplasm enclosed in a delicate wall. The green part contains chlorophyll, starch-granules, and several nuclei ; the branched part is nearly colourless. Simple as it is, Botrydium shows the division of labour and differentiation of function found in all the higher plants. The green bladder represents the **leaves** lifted up on a neck which represents the **stem**, so that the chlorophyll is fully exposed to light. The branching threads thrust into the mud serve as **roots**, first as an anchor or organ of attachment, and secondly to absorb from the mud salts dissolved in water.

In so simple a plant, the food materials absorbed by the green part and by the roots, meet together in the general protoplasm of the body. In higher plants, the plant body is made up of a very large number of cells, and, in accordance with their different positions in the plant, these cells have different functions and different structure. Those in the leaves, for instance, have chlorophyll, and are able to break up carbonic acid and to make starch. But, for the most part, they absorb no water and get no direct supply of nitrogen and salts. The cells of the roots absorb water and salts; but they, having no chlorophyll, cannot use carbonic acid nor manufacture starch. Thus a **division of labour** has taken place, and the cells, with different structures and different functions, are dependent on each other. The plant, instead of being an aggregate of independent cells, has become an organised whole with parts in dependence on each other. There is now not only the structure of cells to be examined, but the structure of the whole plant, the arrangement of the groups of cells.

FIG. 8.—*Botrydium*: the horizontal line represents the surface of the mud above which is the green bladder containing protoplasm and several nuclei, as well as starch granules and chlorophyll; below the line are the colourless branching roots: the protoplasm is not broken up into cells by cell-walls.

In the consideration of such an organised community of cells, the first question that suggests itself is the method by which foods, obtained by one group of cells, find their way to other groups; how, for instance, the leaf cells get their nitrates, or the root cells their starch.

In the simpler many-celled plants there is no trace of vessels or passages along which substances might pass from cell to cell. The substances pass through the protoplasm of the cells and are handed on from cell to cell, creeping through the plant. The protoplasm of each cell is in actual connection with that of adjoining cells, so that the whole plant may be regarded as a continuous mass of protoplasm stretching through and through the cell walls. In higher plants, such as ferns and flowering plants, there are interspaces and vessels containing air and sap, and at first sight it seems probable that gases and fluids containing nutritive substances in solution pass along by mechanical means, as gas and water circulate through the supply pipes of a town, or percolate between the cells like drainage through a gravel sub-soil. But it can be shown that in a number of cases the protoplasm of contiguous cells is continuous through apertures in the cell walls and that the apparently mechanical passage of gases and fluids through vessels and in intercellular spaces is not a mechanical passage, but that it is under control of the protoplasm of cells, varying in amount and in the rate of passage with conditions affecting the activity of the protoplasm of the cells. For instance, the strength of the upward current of sap is much greater than could be caused by evaporation from the leaves, and for a time will go on when the leaves have been cut off. Evaporation from the leaves is not a simple mechanical process, but is controlled by the expansion and contraction of cells guarding apertures in the leaves. We shall be most near the truth if we regard the passage of substances from one part to another part of the plant as being a vital process occurring in the protoplasm of the whole plant, whether the plant be like an oak-tree, a complicated organism of many million cells, or like Botrydium a simple undivided mass of protoplasm.

Retaining in our minds this general idea, it is possible to pass directly to examination of the structure of higher plants—as, for instance, of flowering plants. But this also must be borne in mind; between the flowering plants, with their great complexity of structure, and simple aggregates of cells like Spirogyra, there are innumerable simpler plants, which botanists have been able to arrange in a series of ascending degrees of complexity, so that they seem successive stages in the development of higher plants from lower plants. When we turn to animals we shall find a similar series and examine the stages with some care.

The growth of a plant takes place by cell-multiplication. When the protoplasm in cells increases in bulk, the nucleus and the protoplasm divide and new partition walls grow in between the dividing protoplasm as in Spirogyra. But in Spirogyra the division is always across the length of the cell, and thus threads, composed of rows of cells, are formed. In the tissues of higher plants the cells may divide across any axis according to the nature of the tissue, so that the tissue increases in length, or breadth, or thickness. So there are to be found **linear tissues**, like the vessels of plants, in which the cells have divided across their greatest length, **flat tissues** where the cells divide in length and breadth, as in the outside layer of a leaf, **solid tissues** where they divide across the length and breadth and the depth, as in the substance of a potato.

The young shoot and root of a sprouting seed are almost entirely composed of small cells, all much alike. The cells have very large nuclei and abundant protoplasm. They divide rapidly, and give rise to the various permanent tissues of the plant. This young or embryonic tissue is called **meristem** (Fig. 9), and it is from meristem tissues in the adult plant that subsequent growth of the plant takes place. At the apex of the shoot and the tip of the root, the various tissues meet in the simple meristem of these parts from which new growth is taking place. In many plants, for instance in flowering plants as opposed to palms and grasses, a tube of meristem called the **cambium** runs down the stem from the apex to the tip of the root and forms the growing tissue from which **wood** arises on the inside, **bast** on the outside.

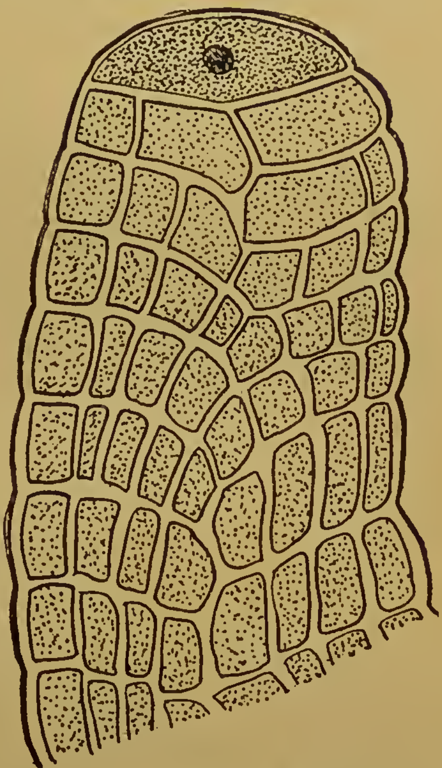


FIG. 9.—Meristem Tissue from the tip of a Leaf-shoot of *Marsilia uncinata*. The large cell at the apex has given origin to the others which are getting arranged in longitudinal rows; each cell has a thin wall surrounding the protoplasmic contents. (From Behrens.)

Other layers of meristem tissue occur in various parts of plants when there is occasion for growth. Thus the bark or cork of trees grows from a special layer of meristem cells to be found immediately under the epidermis. In fact, a young plant consists of a mass of meristem cells rapidly dividing. As the plant grows larger, the meristem cells in various regions become altered into the permanent cells of the adult tissues. These, however, rarely continue to multiply after they have become specialised, and to provide for further growth a set of unaltered meristem cells becomes associated with each tissue, and it is by the multiplication and subsequent specialisation of the meristem that further growth of the tissues takes place.

CHAPTER V

PLANT TISSUES

THE permanent tissues of plants may be divided conveniently into three great systems, each with its own kind of specialised cells and groups of cells. The **outer or epidermal tissues** form the surface layer of the plant in its leaves, shoots, stem, and roots ; they protect it against external agencies, and regulate the intake and output of air, of water, and of food-substances. **The vascular tissues** form bundles of connecting fibres, vessels, and strands, which may be seen as the veins in a leaf, and which run through the stem and the roots, and serve as the special paths along which food-substances, water, gases, and the substances elaborated by protoplasm pass from one part of the plant to the other. **The parenchyma** or ground tissue is the mass of the leaves, and stem, and roots, the tissue which is bounded by the epidermis on the outside, and through which the vascular bundles pass ; in it are the assimilating tissues of the plant like the chlorophyll-containing cells of the leaf, the supporting tissues like wood cells and the fibrous bast cells, growing tissues of unspecialised cells from which new growth is taking place, and tissues in which excretions are stored or starch laid by for future use.

The epidermis is the superficial tissue of young shoots and leaves. On the roots it cannot be distinguished readily from the underlying tissues; on older stems and leaves it may be altered completely by structures which appear later. It is a thin layer of cells covering and protecting the young green parts of plants. It consists usually

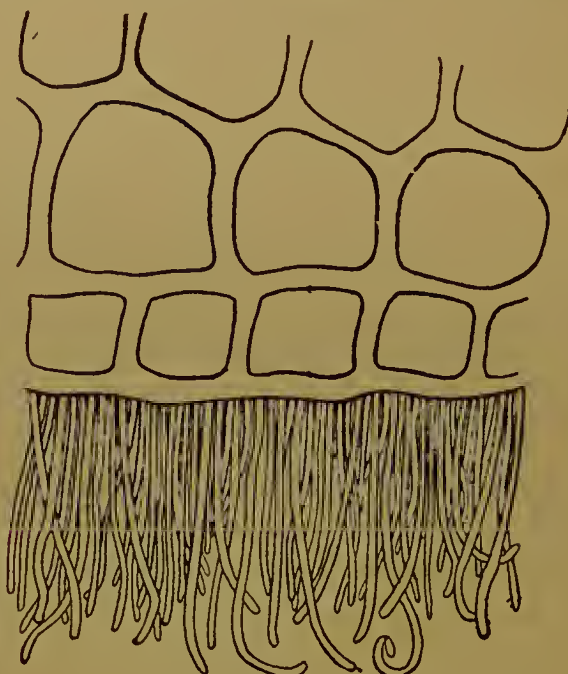


FIG. 10.—Epidermis from Sugar-cane with rod-like waxy secretion. (From Sachs.)

of a single layer of columnar or tabular cells regularly placed and almost invariably without chlorophyll (Figs. 12, 16, 24). The outer walls of the cells frequently are thickened, and a thin pellicle, the **cuticle**, often runs continuously over the outer surface of the cells. The material of the cuticle is very resistant to the passage of water, and differs chemically from cellulose, for it is not turned blue by iodine and sulphuric acid. Another protection against the passage of water, especially against its passage inwards, is the excretion of wax on the outer surface. This wax appears as little warts or rods, and causes rain or water to collect in little drops instead of spreading over the surface of the plant and really coming in contact with the living tissues. The "bloom" on fruits is a familiar instance. But water has to pass out of the plant so that there may be room in the tissues for the intake of water absorbed by the roots and containing new supplies of inorganic salts. Everywhere on the epidermis, but especially on the under surface of the leaves, there are numbers of minute openings called **stomata** (Fig. 11). If a thin piece of the epidermis from the leaf of any plant be stripped off and placed in water under the microscope, the stomata are seen at once. For they are guarded by minute oblong cells filled with chlorophyll granules and so are conspicuous, by their green colour, among the uncoloured epiderm cells. Between these **guard cells**, which are oval in shape, and usually two in number, lies a minute aperture leading into a small cavity which communicates with the intercellular spaces in the spongy tissue of the leaf (Fig. 12, 2). In damp weather, when the air is nearly saturated with moisture, the guard cells alter their positions so as to open the stoma as

FIG. 11. — Epidermis from under surface of a lilac leaf, showing three Stomata each enclosed by a pair of guard-cells.

widely as possible. In dry weather, when the air might withdraw water too rapidly from the tissues of the plant, the guard cells contract the aperture to the smallest point.

The stomata normally serve for the transpiration of gases, especially of water-vapour; but, in a few cases, stomata situated at the edges of leaves serve for the extrusion of water in the liquid state.

The **hairs** of plants are outgrowths from the epidermis.

FIG. 12.—Vertical Section through a Stoma on the under surface of a Leaf: **1.** Aperture between the guard-cells. **2.** Intercellular space communicating with spaces among the parenchyma cells. **3.** Epidermis cells with cuticle as the lower (outer border). (After Sachs.)

At first, hairs are mere processes from single epiderm cells; but by growth and cell-division they may be changed into multicellular organs. Some hairs are glandular, and in a little knob at the end of the outgrowths is collected the secretion of oil, or resin, or gum. In some cases, as in the nettle, an acrid secretion with irritant properties is collected, and liberated when the hair is broken off.

The cells of the epidermis frequently have the cellulose of their outer walls changed to **cork** to prevent evaporation of sap. After the first or second year of their existence very many plants develop a thick layer of cork cells within the epidermai layer, which dies. Cells in a row under the epidermis multiply rapidly, and the layers of cells to which they give rise form a compact tissue with no spaces between the cell-walls. The contents of the cork cells disappear and become replaced by air ; the walls of the cells change from cellulose to cork, and the tissue forms a thick protective layer completely resistant to the passage of water (Fig. 14).

The second system of tissues, the **fibro-vascular bundles**, is so characteristic of higher plants that, in classification of the vegetable kingdom, those without vascular bundles (the Algæ, Fungi, Lichens, Liverworts, and Mosses) are distinguished as *cellular* plants from the *vascular plants* (Ferns, Lycopodiums, Equisetaceæ, &c., and the seed-plants). Even in the cellular plants, however, not infrequently there are tracts or bundles of elongated thin-walled cells, distinct from the tissue in which they are

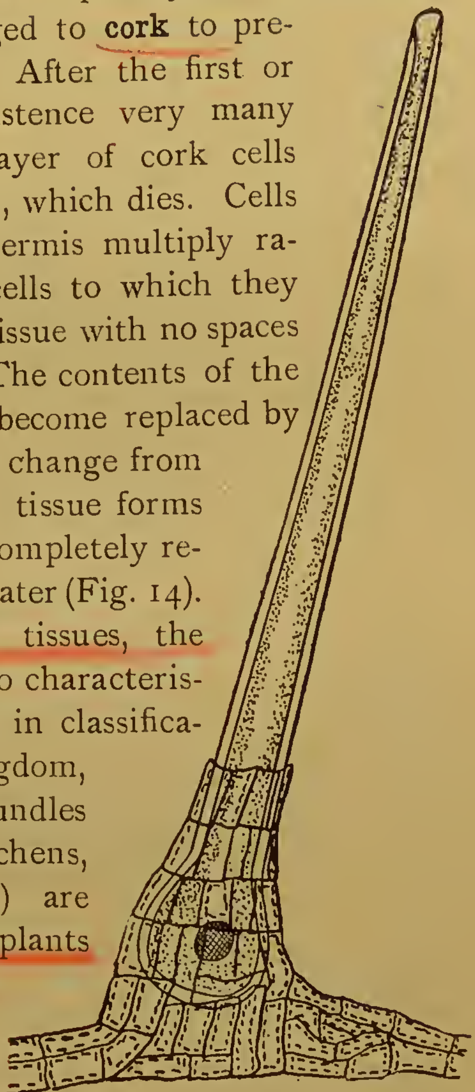


FIG. 13.—Stinging-hair of Nettle. This is a single elongated cell with nucleus in the bulbous root which is surrounded and protected by epiderm cells.

embedded, and serving as the main channels along which substances pass from part to part of the plant. The vascular bundles of vascular plants (Fig. 15) run as thin threads of specialised tissue through the whole plant. In the root there is usually one strand lying in the axis, and receiving branches from the lateral roots. The

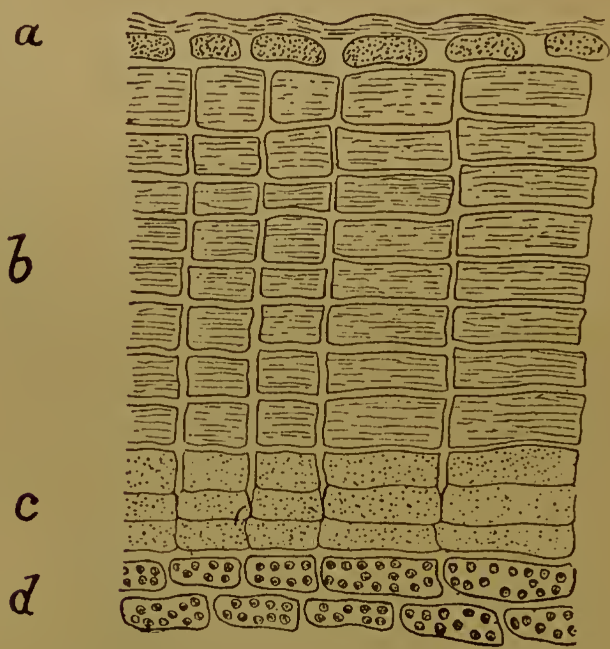


FIG. 14.—Section through one-year-old shoot of *Aïlanthus glandulosa*, showing, **a**. Dead epidermis. **b**. Cork cells. **c**. Cork cambium. **d**. Cortex cells with chlorophyll granules. (After Prantl.)

vascular strands of the roots pass into those of the stem, which are usually symmetrically arranged round the periphery. These give off branches to the leaves, and finally pass into the growing point at the apex of the stem, where they lose themselves in unspecialised cell tissue. The details of their arrangement in the stem vary much in different plants, and depend on the arrangement of the leaves. The separate bundles are placed round the margin of the stem: between the nodes, or where leaves grow out, they appear as separate wedge-shaped masses; at the nodes they fuse together, and the branches for the leaves are given off.

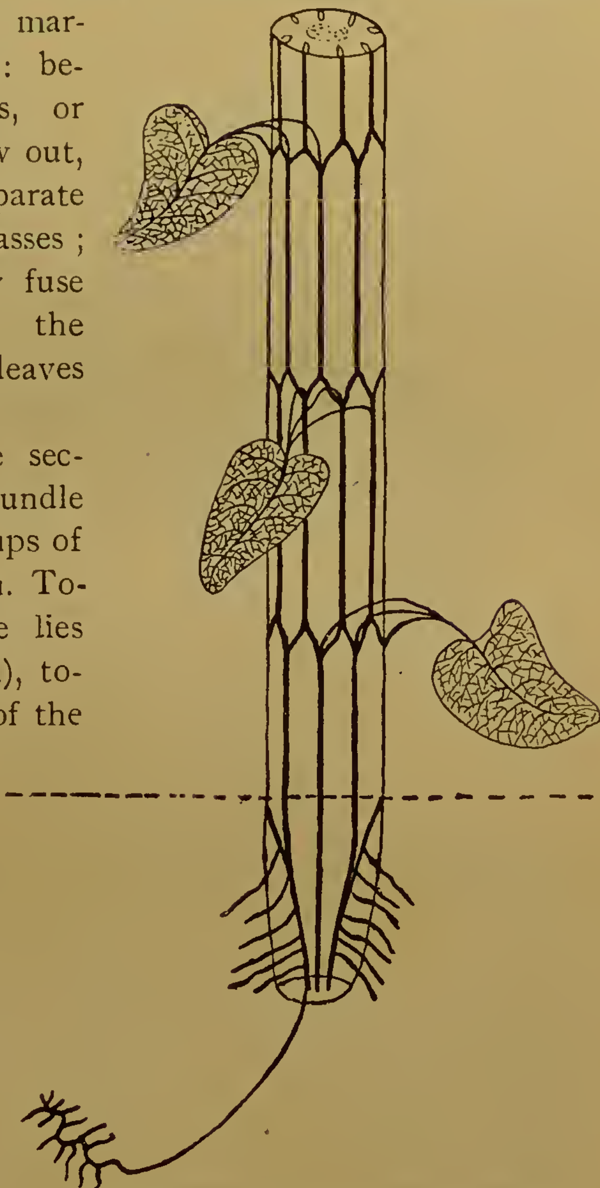


FIG. 15.—Diagram of the course of vascular bundles in stem, leaves, and roots.

In a transverse section of a single bundle (Fig. 17) two groups of structures are seen. Towards the outside lies the **Bast** (**Phloem**), towards the centre of the stem the **wood** (**Xylem**). The whole bundle usually is surrounded by a sheath of thick-walled cells belonging to the ground tissue. Within this, the bast portion and the wood portion can be seen to consist of cells, rather narrow in transverse section, with here and there wider ring-shaped spaces. The cells lie closely packed together, and there are no spaces between them. The wood portion contains the larger vessels, and serves chiefly for the passage of air and water; even the largest circular spaces in the bast portion are, in the fresh condition, filled with albuminous slime, and do not serve for the passage of air. In other words, the proteids and albuminous substances pass

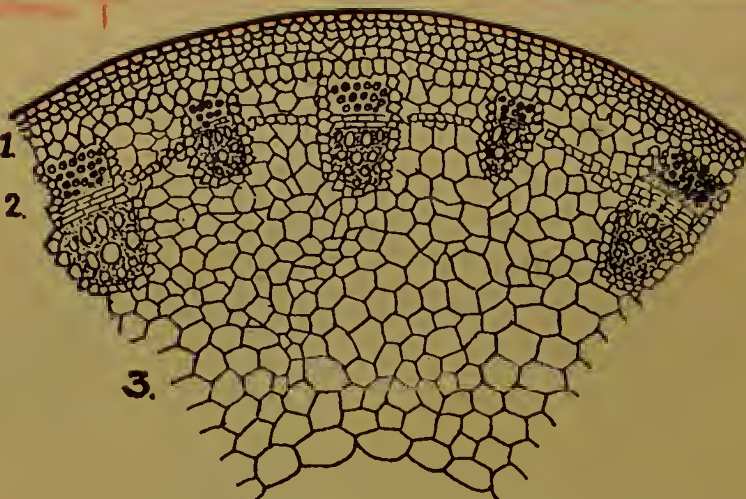


FIG. 16.—Part of a Transverse Section through the Stem of a Dahlia, showing—**1.** The epidermis; **2.** Five fibro-vascular bundles; **3.** Parenchymatous tissue.

downwards through the bast portion; air, water, and the salts soluble in water pass through the wood. Although generally the bast lies to the outside and the wood to the inside, in some cases—*e.g.*, in ferns—the xylem is surrounded by the phloëm.

If we examine the minute structure of the cells in typical higher plants, by transverse and longitudinal sections, we shall learn the characters of the constituents of the bundle. The outer portion of the bast is made up chiefly of elongated cells with thick cell-walls. In transverse section (Fig. 17. *d*) these cell-walls appear to form

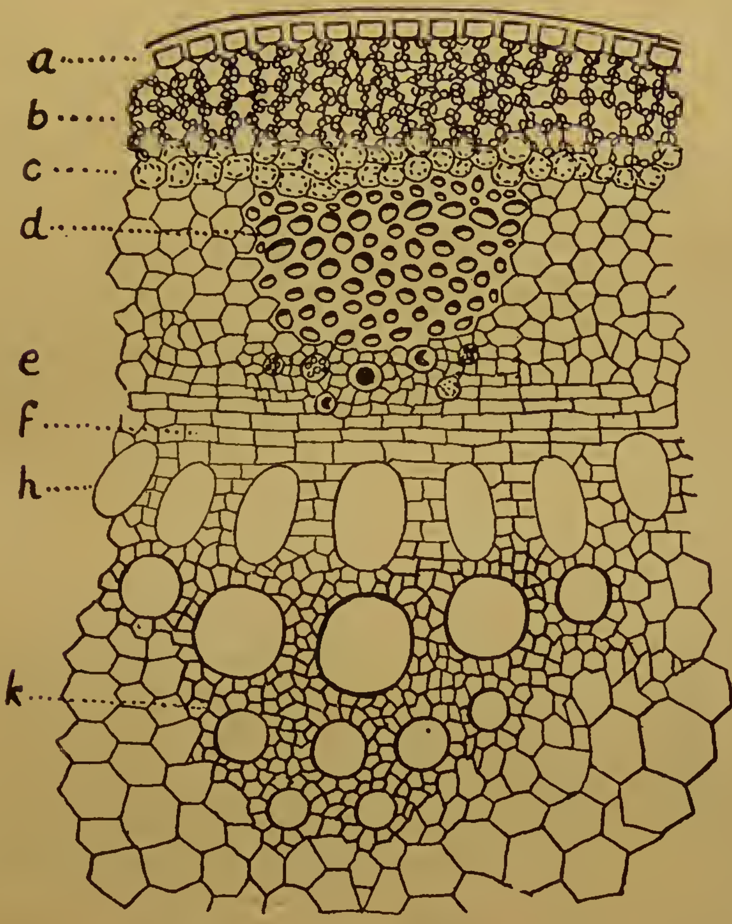


FIG. 17.—A Single Bundle from Fig. 16, enlarged. **a**. Epidermis with cuticle. **b**. Collenchymatous cells. **c**. Cells with chlorophyll. **d**. Hard bast; below this, opposite **e**, is soft bast parenchyma containing sieve-tubes, some cut across through the sieve plates, others cut through the albuminous mass stretching between the sieve plates. **f**. Cambium. **h**. Outer row of wood-vessels; nearer the centre are three other rows containing a diminishing number of vessels. **k**. Wood parenchyma.

a continuous thick network. In longitudinal section it is seen that the cells (Fig. 18. *a*) are elongated, that the ends of adjacent cells overlap each other, and that the elongated cells form a close meshwork, as the cells are not perfectly straight, but are occasionally twisted round each other. This layer is called the **hard bast**, and forms a dense, partly elastic, protective tissue. In the interior of the cells, remains of the protoplasmic contents occasionally are visible. But more often the cells are transformed practically into elastic fibres. Chemical investigation shows that the cell-wall is not cellulose; it does not stain blue with sulphuric acid and iodine, and resists the action of sulphuric acid like the cuticle, or like cork cells. In distinguishing the hard bast cells and many other vegetable cells, a useful staining reagent, called chlor-zinc-iodine, may be employed.[1] This mix-

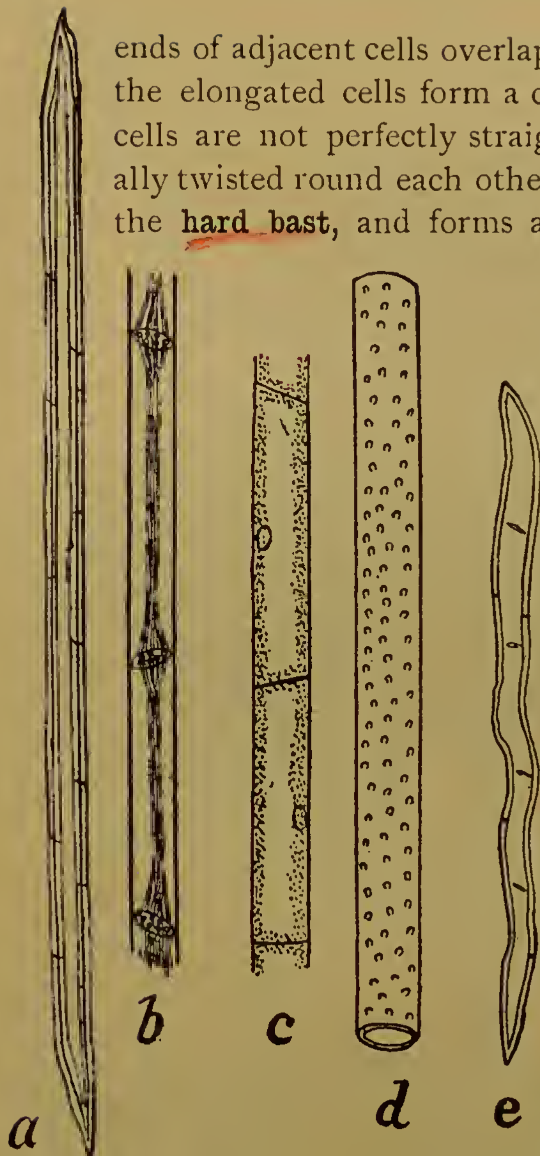


FIG. 18.—Isolated Elements of a Vascular Bundle. **c**. Cambium cells; **b**. Sieve-tube. **a**. Bast-fibre. **d**. Dotted wood-vessel. **e**. Wood-cell. **a** and **b**, the bast elements, and **d** and **e**, wood elements have alike been formed from cells like **c**.

[1] Chlor-zinc-iodine, or Schulze's solution, can be obtained from

ture stains protoplasm dark brown ; by the action of the chloride of zinc cellulose is turned into starch, and then stained blue by the iodine, but the bast-fibres show their difference from cellulose by staining yellow.

Lying nearer the centre of the stem on the inner side of the hard bast comes the so-called soft bast. The characteristic part of this tissue is what are called sieve-tubes (Fig. 18. *b*). The younger stages of sieve-tubes may be seen lying alongside the adult vessels. These stages consist of elongated cells placed end to end, with thin cellulose walls and protoplasmic contents. In adult sieve-tubes the partitions separating the ends of the cells become pierced by many minute apertures, and form sieve-like plates. The protoplasm forms a strand passing down the centre of each cell, and is expanded into a brush at either end. The ends of the brush pass through the sieve pores into direct connection with the similar brush in the adjacent cell (Fig. 19). Where the lateral walls of sieve-tubes come together, similar sieve-plates and protoplasmic connections are formed. Thus the sieve-tubes form a definite continuous chain of protoplasm running along the fibro-vascular bundle, and serving as the main path along which proteid materials pass.

Lying closely applied to sieve-tubes are **companion-cells** (Fig. 19)—elongated small cells, looking as though they had been cut out of the sieve-tubes. On staining with chlor-zinc-iodine, the cell-walls of the sieve-tubes, of the companion-cells, and of the young sieve-tube cells assume a blue colour, showing that they are cellulose ; the

dealers in microscopic reagents. It is prepared by dissolving zinc in hydrochloric acid, evaporating to a syrup, and mixing with a solution of iodine in potassium iodide dissolved in water.

protoplasm of the cells stains dark brown. In a typical stem there is to be seen, lying in the middle of each bundle, between the bast and the wood, a layer of cells with thin walls and plentiful protoplasmic contents. Chlor-zinc-iodine shows that the walls are cellulose, and that the brown-staining protoplasm occupies practically the entire space of the cell. This layer is the **Cambium** layer (Fig. 17. *b*), and from it the bast is formed on the outside and the wood vessels on the inside. It is a layer of cells not differentiated, but serving as an active centre of growth. Towards the centre of the layer the walls of the cells are in transverse section nearly square; in longitudinal section they appear as elongated cubical cells (Fig. 18. *c*). Active division is taking place, and next the wood and the bast, the cells split off from the cambium form a transition series leading to the specialised cells of the wood and of the bast.

FIG. 19.—Enlarged view of longitudinal section through a Sieve-tube in the region of a Sieve-plate. On either side the sieve-tube lie *companion cells*.

The **wood or xylem** (Fig. 17. *h–k*.) is conspicuous by the size and width of the cut ends of vessels seen in transverse section. These vessels are arranged for the most part in radial rows, the larger vessels lying towards the cambium side of the bundle. They are formed by a series of elongated cells placed end to end, and with the walls at the end partially or completely absorbed, thus giving rise to vessels. The walls are lignified, and with chlor-zinc-iodine assume a yellow colour instead of the blue of cellulose. Protoplasmic contents are absent, and the vessels during life contain gases or water. The walls of the vessels are sculptured in various ways, and this sculpturing causes the kinds of vessels to receive various names. In "dotted" vessels (Fig. 18. *d*), thickly scattered over the cell-walls are small round pits which have been

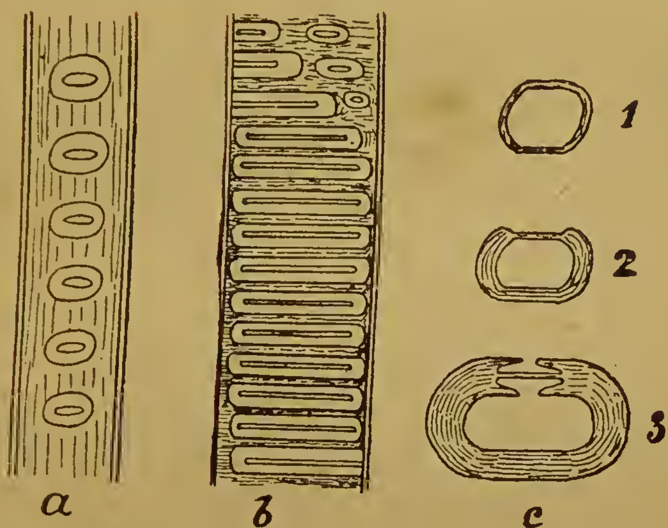


FIG. 20.—Diagram of Bordered Pits and Scalariform Vessel. a. Vessel with bordered pits. b. Scalariform vessel with elongated bordered pits. c.—1. Cross section through vessel with unthickened wall. 2. With wall thickened except in region of pit. 3. Wall still more thickened and bordered pit formed by ingrowth of pit edges.

formed by small areas of the cell-wall remaining quite thin while the cell-wall in general becomes thick. When this happens in the partition wall separating two cells, there are formed two pits opposite each other and separated from each other by a thin membrane, the original cell-wall. When the cell-wall is unusually thick, the pits appear like fine canals. A special kind of pitting, frequently present in all plants, is so abundant and well-marked as to be characteristic in the wood of conifers. In this case the original thin area is large, but the thickened cell-wall round the border of the pit grows inwards leaving open only a narrow slit. These, seen in surface view, appear like pits with definite borders round them—the ingrowths of the cell-walls over the pits—and are hence called **bordered pits** (Fig. 20. *a*). In the Ferns these bordered pits are very broad, reaching half-way round the vessels. The thickened borders thus extend at regular intervals across the vessels with the slits opening into the pits between them. The arrangement is not unlike the rungs of a ladder, and hence the vessels so marked have been called **Scalariform vessels** (Fig. 20. *b*). When the pits are irregularly placed, and elongated in various directions, the thickened borders give an **irregularly reticulated** appearance to the walls of the vessel, and transition forms may be seen between these and vessels where the thickenings form regular spirals, twisted once, or more than once, round each vessel. These **spiral vessels** (Fig. 21. *g*) are most abundant and have coils most closely wound in the centre of the xylem. Finally, among the

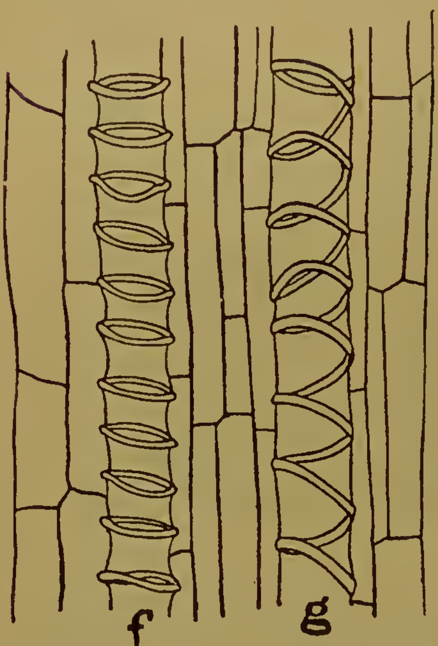


Fig. 21.—Longitudinal Section through the Xylem of vascular bundle from *Impatiens balsamica* showing—g, spiral, and f, annular vessel.

vessels may be noticed **Annular** vessels with the thickenings arranged in rings, but in mature stems these rings are usually more or less disorganised (Fig. 21. *f*). In the xylem there are also **wood-fibres** (Fig. 18. *e*) present. These are long and pointed cells with their walls lignified and pitted, and in which the protoplasm has completely disappeared. The wood-fibres are so twisted and matted that even in a longitudinal section the whole length of

FIG. 22.—Parenchyma from Potato Tuber containing Starch Granules.

a cell rarely appears. Finally there are to be seen in the xylem, oblong cells with square ends frequently pressed against the sides of the vessels so that they encroach on the cavity of the vessels. These cells retain the thin cellular wall of unspecialised cells and retain their protoplasm (Fig. 17. *k*).

The fundamental or general tissue of plants consists in its simplest and most common form of irregularly-shaped thin-walled cells—called **parenchymatous** cells. It may be seen in any young plant practically occupying all the space within the epidermis (Fig 16. 3)—except of course the space occupied by the vascular bundles. In the typical condition, the cells are large, and are actively multiplying. Where cells are in contact, a single cell-wall separates them, but at the angles where three cells meet, interspaces occur, due to splits in the cell-wall. The cells contain protoplasm and a nucleus, but the products

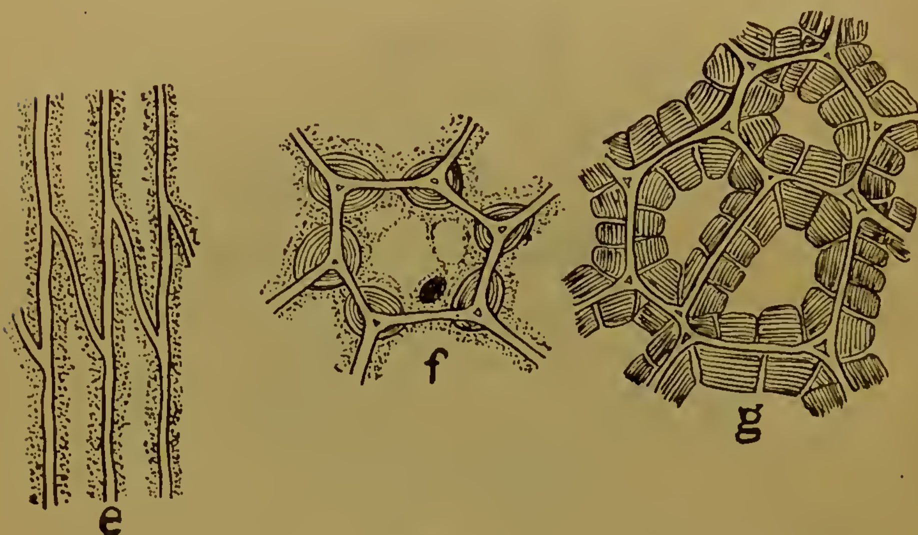


FIG. 23.—e. The overlapping ends of prosenchymatous cells. f. Collenchymatous cells. g. Sclerenchymatous cells.

formed by the protoplasm are so plentiful that the protoplasm occupies a narrow area within the cell-wall. The remaining space is occupied by a watery juice full of substances of nutritive value. Reserve materials like the starch in the tubers of the potato, in the pith of young plants, or in seeds are to be found in parenchymatous cells (Fig. 22). Frequently in old plants, and in old tissues of plants there are to be found parenchymatous cells practically dead. The protoplasm, the sap and starch grains have disappeared, and the cell-walls remain behind as a spongy pith filled with air.

When the cells of fundamental tissue are elongated they may have overlapping ends, and are called **prosenchymatous** cells (Fig. 23. *e*). When they have pad-like thickenings of the cell-wall at the angles where cells are in contact, they are known as **collenchymatous** cells (Fig. 23. *f*); and where the whole cell-wall is excessively thickened and partly turned into wood, the tissue is called sclerenchyma—the cells **sclerenchymatous** cells (Fig. 23. *g*). These names are merely descriptive, and are applied to cells of different natures in different parts of a plant. Thus the cells forming the hard nodules in the flesh of pears have their walls lignified, and are sclerenchymatous; the elastic fibres of the bast (hard bast) have thick walls not lignified, and are also sclerenchymatous; while the cell-walls of the "bundle" sheath found surrounding the vascular bundle in young stems are frequently lignified, and are again named "sclerenchymatous." A very characteristic feature in the thick walls of sclerenchyma is the presence of small canals formed from pits.

It is in fundamental tissue that most of the chlorophyll of green plants is to be found. Obviously, as the usefulness of chlorophyll depends on its exposure to light, it is found in the leaves and in the stem. As, moreover, the utility of chlorophyll depends on the ready access of air in order that the carbonic acid may be absorbed, the tissues containing chlorophyll have for the most part a loose and almost spongy arrangement of cells. The interspaces between the cells are in free connection with each other and with the stomata, so that the stomata, while serving chiefly for the transpiration of water-vapour are a ready means for entrance of air. Such a spongy structure is well seen in a section through the leaf of a plant (Figs. 24 and 25). In many leaves,

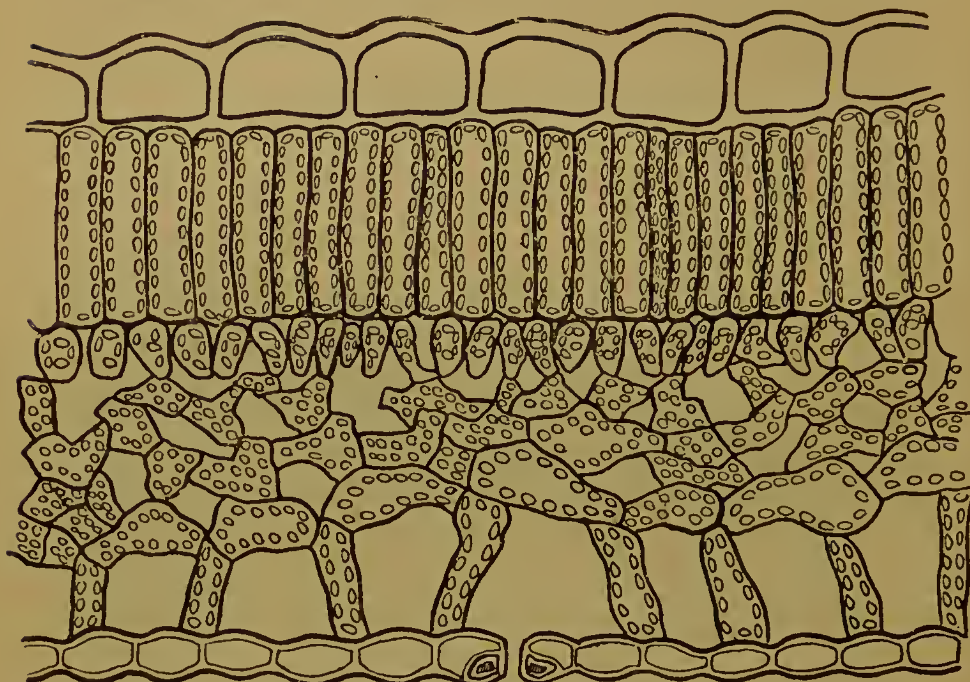


FIG. 24.—Cross section through the Leaf of a Beech. Showing at the top the epidermis cells without chlorophyll, then the palisade layer with chlorophyll, then spongy layer with all the cells containing chlorophyll and with many air spaces between the cells, lastly the epidermis of the under surface with a stoma. The chlorophyll corpuscles are the small oval bodies lying chiefly round the edges of the cells. (After Prantl and Vines.)

lying directly under the epidermis is a layer of elongated cells containing chlorophyll (the "palisade" layer), and below that is the spongy parenchyma (Fig. 24). In higher plants the chlorophyll is present in definite small corpuscles which like the chromatophores of Spirogyra consist of a proteid substance impregnated with the green pigment. These chlorophyll granules are present in varying numbers. In the cells of some plants there are very many ; in the cells of others fewer, and it is in general true that in lower plants the chlorophyll corpuscles

FIG. 25.—Cross section through Leaf of *Selaginella*, showing the epidermis containing chlorophyll, spongy parenchyma in the middle of which a fibro-vascular bundle has been cut through, and the epidermis of the under side with stomata. The chlorophyll bodies are large and irregular, and contain starch granules. (After Sachs.)

are fewer in number, larger, and less definitely shaped, than they are in higher plants (Fig. 25).

Chlorophyll corpuscles arise from colourless bodies **(leucoplastids)** present in young cells. When mature, they have the power of arranging and re-arranging themselves in the cells they inhabit, under the stimulus of light. When kept in the dark for some time the green colour changes to yellow, and the corpuscles break up. The autumnal colours of leaves are due partly to changes of this kind.

CHAPTER VI

THE YEAST PLANT

IN green plants the cells containing chlorophyll, while in the presence of sunlight break up carbonic acid taken from the air, liberate oxygen, and use the carbon to build starch. In the absence of light the formation of starch ceases, and the normal respiration of all protoplasm occurs, *i.e.*, oxygen is taken in, and carbonic acid is given out. But the cells in the stem and in the root, cells without chlorophyll and removed from light, never build starch for themselves, but live upon starch manufactured in the green parts and brought down to them through the tissues in the form of sugar. Their protoplasm, therefore, uses oxygen and gives out carbonic acid. A number of plants, like moulds and funguses, have no chlorophyll to build up starch, and live therefore on starch or sugar manufactured by other organisms. Having no chlorophyll, they are independent of light, and take in oxygen and give out carbonic acid. In other respects, too, many of them are similar to those cells of higher plants which have no chlorophyll. They take in water and mineral salts, and from these, with the aid of the sugar supplied them, they are able to elaborate their protoplasm. But it is still more common that they should be unable or "unwilling," even when they are given sugar, to build up proteid material from inorganic substances. Thus none of them make starch, but must be supplied with starch or sugar; a few will build up proteid material from simple inorganic substances; most require complicated compounds of nitrogen, like ammonium tartrate, and these, preferably, will avoid the use even of ammonium tartrate if they can procure ready-made proteid material.

One of the simplest of them is the yeast fungus, *Saccharomyces cerevisiæ*. The pale yellow, frothy substance known as brewer's yeast, which rises as a scum on the surface of fermenting vats, and which is used by bakers to make dough "rise," consists of a fluid in which are suspended immense numbers of minute particles just visible with a low power. Each of these particles is a single-celled organism—the yeast plant. Under the higher power of the microscope the yeast plant appears a small round cell with a very thin cell-wall and granular contents. The cell-wall is so thin that it cannot be seen definitely, until the protoplasm has been stained by some fluid like magenta. A few taps with a needle on the cover-slip burst the delicate cells, the coloured protoplasm emerges, and the crushed walls remain behind like empty grape skins. The granules in the protoplasm consist of fat and of proteid material, and there are usually present spaces of irregular size and shape, called **vacuoles**, and filled with a transparent fluid. The nucleus is invisible in unstained specimens, or even in specimens stained by iodine and magenta. But more complicated methods reveal its presence.

Yeast cells in the liquid from a brewer's vat are in a favourable position for growth, as they are in an abundant supply of food. Various stages of reproduction by budding (Fig. 1. *c.*) are always to be found. A very young bud is a small protrusion of the protoplasm, covered by a protrusion of the cell-wall. As the bud grows, its wall gradually becomes round and finally closes off the bud from the parent cell. But the budding may take place so rapidly that a young bud begins to throw out buds itself before it has separated from the parent. Moreover, the same cell may give rise to more than one bud at the same time, so that little colonies of yeast cells are frequently found.

When the conditions are unfavourable for growth—as, for instance, when yeast is kept so long in a fluid that all the available nourishment has been used up, it prepares to tide over unfavourable conditions by another method of reproduction. In cells starved in this way, part of the protoplasm breaks down—the plant, in fact, feeds on itself, and there results the curious paradox of cellular starvation—that fat, due to the breaking down of protoplasm, is deposited in the cells. Then the scanty protoplasm breaks up into four little round bodies, arranged in a pyramid in the centre of the cell. Round each of these four a very thick cellular wall is deposited and they form what are called spores. Ultimately the cell-wall is ruptured and the spores emerge. These are peculiarly able to retain their vitality under unfavourable conditions. If the liquid dries up, the spores form a light dust which gets blown about, and so serves to spread the plant from place to place. They retain their vitality for long, and, as soon as they find their way to a nutritive fluid again, they develop rapidly into the ordinary form of the plant.

The formation of spores can be observed readily if some yeast be spread on a thin slab of plaster-of-Paris kept moistened with water under a bell jar, or if it be grown on a slice of potato.

The yeast plant, like some other low organisms, possesses the peculiar property of causing **alcoholic fermentation.** The "sweet-wort" from which beer is made is malt dissolved in water. Malt is made from grains of barley which have been allowed to sprout, and then killed by heating. In the process of sprouting a large part of the starch contained in the grain is turned into what is called grape sugar. This sugar, along with some of the proteid material and the mineral salts contained in the barley, is dissolved in the wort. Yeast, placed in this, has the necessary food materials--sugar, mineral salts and proteid—and it multiplies very rapidly. Large quantities of carbonic acid are given off, the sugar gradually disappears, and alcohol is formed in the liquid. By careful experiment it has been shown that only about one per cent. of the sugar is used as food by the yeast-cells in their growth and multiplication, and the actual amount of carbonic acid expired by them must be very small. But their presence excites a peculiar chemical change in the great mass of sugar, by which it is split up into carbonic acid and alcohol. It is this carbonic acid that is given off in such quantities that, if a little yeast be put in a teaspoonful of wort in a test-tube, in a few minutes the upper part of the test-tube will be so full of carbonic acid that a burning match, thrust into it, will be immediately extinguished.

Chemically, the process of alcoholic fermentation excited by the yeast plant is as follows :—

Grape Sugar.		Alcohol.		Carbon Dioxide.
$C_6H_{12}O_6$	=	$2(C_2H_6O)$	+	$2(CO_2)$.

It must be remembered that this is a side issue of the life of the plant : the alcohol and the carbonic acid are not the direct result of the changes in the plant protoplasm. The yeast plant, like many other low organisms, is what is called a living or organised **ferment.**

In brewer's wort, the yeast plant obtains its nitrogenous food in the form of proteid. Pasteur has shown that proteid is not necessary to its growth, but that a solution containing ammonium tartrate as the only supply of nitrogenous food is sufficient. Thus, yeast stands intermediate between the cells of green plants and the cells of animals. Like animals it will absorb proteid directly ; unlike plants it cannot build up proteid when supplied with nitrogen in the simple form of nitrates. But, given the more complicated form of ammonium tartrate $(NH_4)_2\ C_4H_4O_6$ it can complete the elaboration of proteid. M. Pasteur invented an artificial wort in which the yeast plant multiplies rapidly and sets up alcoholic fermentation.

Pasteur's Solution is as follows :—

Water, H_2O	83·76	per cent.
Cane sugar, $C_{12}H_{22}O_{11}$	15·00	"
Ammonium tartrate $(NH_4)_2\ C_4H_4O_6$	1·00	"
Potassium phosphate $K_3\ PO_4$	0·20	"
Calcium phosphate $Ca_3\ (PO_4)_2$	0·02	"
Magnesium sulphate $MgSO_4$.........	0·02	"
	100·00	

In this, fermentation goes on most actively at temperatures between 28° and 34° C.; at low temperatures it ceases; at 38° all growth stops. If the liquor be boiled, the plants are killed and the process permanently is arrested. The process goes on equally well in darkness or in light. It will occur in the absence of oxygen, so showing that the yeast plant is able to obtain its oxygen by chemical decomposition of its food. Free oxygen, dissolved in the solution, stops the process, and carbonic acid has no effect upon it. Thus in the yeast plant we have an organism remarkably independent of all conditions but its food, and, as all manner of food solutions have been tried and Pasteur's solution is found to be the most suitable, we can get a close knowledge of the process of life in this case. The water in the solution is needed directly, as a food for the plant, and indirectly that it may get its food in the suitable condition of solution. The sugar is not necessary to the life of the plant; it grows, although very slowly, if sugar be omitted from the solution, obtaining the necessary carbon from the ammonium tartrate; but sugar is required for active growth and to exhibit the power of the plant as an alcoholic ferment. The ammonium tartrate is necessary; without it, unless proteid is directly supplied, all growth ceases. The three mineral ingredients—potassium phosphate, calcium phosphate, and magnesium sulphate—give the mineral constituents found in the ash of the yeast plant, which always contains potash, lime, magnesia, and phosphoric acid, while sulphur is given off in the process of burning.

CHAPTER VII

BACTERIA

IF a drop of water on a slide be stirred with a paint-brush dipped in gamboge, and the drop be then covered with a slip, and examined under a high power of the microscope, the exceedingly minute particles of the gamboge become visible. These minute particles are not at rest, but ceaselessly vibrate to and fro, each within a space about two or three times the size of the particle. Such "**Brownian movements**" can be observed in all minute bodies suspended in a fluid, and one must distinguish carefully between Brownian movement and actual vital movement, in any organisms that are small enough to show Brownian movement.

All animal and vegetable substances that are rotting swarm with the minute organisms known as **Bacteria or Microbes.** A drop of milk or soup that has "gone bad," or a little of the soft matter scraped from a decaying potato or from a hyacinth bulb in water that has begun to smell instead of to sprout, all show under the microscope innumerable minute bodies just on the borderline of invisibility, and, like the grains of gamboge which they

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resemble in size, vibrating to and fro. When the eye becomes accustomed to their minuteness it is seen that while some merely vibrate, others actually progress through the fluid. Some are round, others oblong, straight or curved, thin or thick, and many are arranged end-to-end in threads or spirals. It is perfectly clear that in such cases there is a collection of organisms with different shapes and sizes, with different habits and movements. Until a method had been invented by which the forms of bacteria could be sorted out, and studied by themselves, no exact information was possible. Now that it has been discovered, the best of these methods seems very simple. A gelatinous preparation in which bacteria will grow abundantly, but which has been boiled to kill any already in it, is melted, and a drop of the fluid containing the bacteria is shaken up with a small quantity of the liquid jelly. A drop of this is shaken up with another quantity of the jelly, and this process may be repeated several times. As bacteria are much smaller than $\frac{1 \text{ inch}}{10000}$, in the small drop taken, a million might easily be present. Suppose the quantity of jelly to be 100 times the size of the drop, a drop taken out of this would contain about 10,000 bacteria. A second dilution would reduce the number to 1,000, a third to 10. The jelly in a liquid condition is poured upon a glass plate and cooled in a very thin layer. The ten bacteria (in this hypothetical case) are fixed here and there in the jelly. When the plate is kept in a suitable place the bacteria begin to multiply, each giving rise to a colony like itself, and these colonies grow quite large enough to form patches visible to the naked eye. The colonies of different bacteria can be identified by their shapes and colours, by their modes of growth in different media and so forth, and "pure cultivations"—*i.e.*, cultivations containing only one kind of bacterium—may be made by inoculating jellies from the various colonies on the first mixed plate. By such methods, an enormous number of different microbes have been studied. They all consist of a delicate cell-wall, in most cases formed of cellulose, and protoplasmic contents. These contents stain deeply with the kinds of stains that colour the nuclei of larger cells, and no distinction between protoplasm and nucleus has been made out in them. Some microbes have at one end or at both delicate vibratile **flagella** by the movements of which they are driven or pulled through the water. Others apparently are motionless, save for "Brownian movement."

Definite names have been given to some of the most common shapes in which microbes appear (Fig. 26). Thus, minute round forms are called **Micrococci**; larger round forms, **Macrococci**; oblong forms not twice as long as they are broad are called **Bacteria**; oblong forms more than twice as long as they are broad are called **Bacilli**; a flattened, spirally-twisted form is called **Spiromonas**. When food is abundant and the conditions of life favourable bacteria increase in length, and by repeated division across the long axis form jointed filaments or threads. When micrococci reproduce in this way they form **Streptococci**. Unbranched threads are called "**Leptothrix.**" Where occasional longitudinal division occurs and so branches are formed, the filaments are termed **Cladothrix**. When the filaments are short, with slight undulating curves, the name **Vibrio** is applied, while **Spirillum** consists of short, rigid curves, twisted like a corkscrew. **Spirochaetes** are long, thin filaments with the individual curves short and slender.

There are many other forms, and considerable doubt

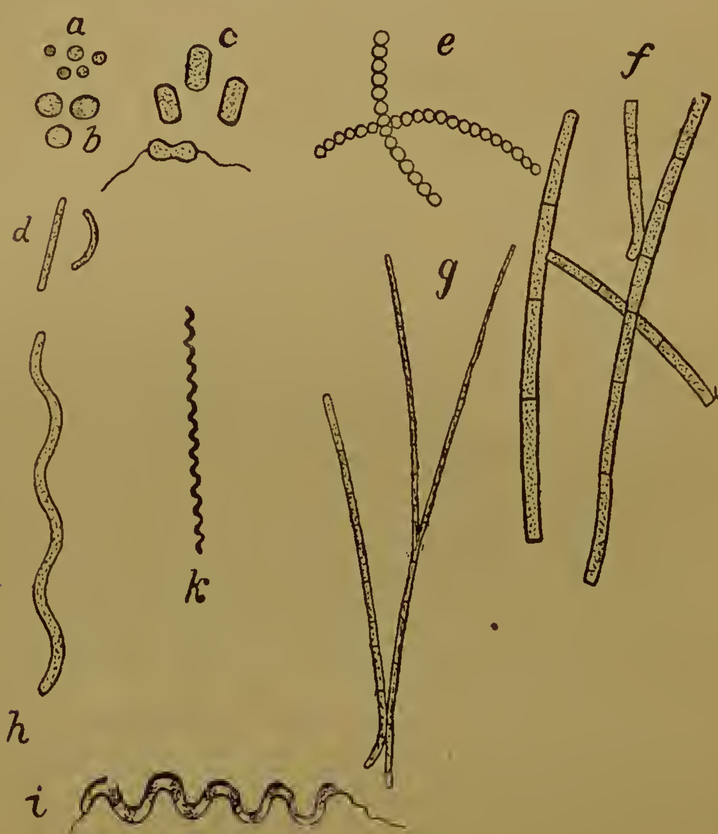

FIG. 26.—Forms of Bacteria. a. *Micrococci.* b. *Macrococci.* c. *Bacteria.* d. *Bacilli.* e. *Streptococci.* f. *Leptothrix.* g. *Cladothrix.* h. *Vibrio.* i. *Spirillum.* k. *Spirochaete.*

exists as to how far microbes with definite history and properties can be identified with individual shapes.

When food is scarce or the conditions of life unfavourable, reproduction by spore formation occurs. The protoplasm becomes granular, a small bright spot appears in it, and this spot increases in size until it may bulge out the wall of the cell. Spores may be round, ovoid, or rod-shaped. They are always colourless, but glisten under the light. They have an exceedingly thick, firm wall, and are liberated by the decay of the cell in which they were formed. Occasionally spores are formed by fission: in a dividing chain or filament here or there are formed large spores called **Arthrospores**, because of the jointed appearance given to the filament in which they appear.

These spores are the great means by which microbes survive unfavourable conditions, and spread from place to place, until, reaching a situation where moisture, temperature, and food are satisfactory, they give rise to the vegetative, rapidly multiplying form.

Innumerable quantities of spores are formed: they may be blown about as a fine dust by the air, or may be carried by currents of water. They will remain undeveloped for practically an indefinite time, if no favourable conditions occur.

In air, in water, in drains, in the soil, in the dust, in crevices between the planks of floors, they are always present. They are light enough to be wafted about by currents of air, but in a still or windless place they gradually sink to the ground. Thus, in the morning, when a room has been quiet all night, there are few in the air; after the housemaid has disturbed things by sweeping the floor, they are to be found in abundance. In the air of a well-flushed culvert few are present; when the flow of water gets low they reach the air from the dry crust deposited on the sides uncovered by water.

Most microbes live on organic substances and are unable to build up their protoplasm out of inorganic materials. Hence the vast majority of them flourish in decaying organic matter, in the bodies of animals or plants, or in the soil. A few, however, are known to contain chlorophyll and to live like *Protococcus*. Disregarding these, microbes can be divided into two classes, those like the yeast plant, that can obtain the oxygen needed for all living protoplasm from chemical compounds, and those that require a supply of free oxygen. The first class are called **Anaërobic,** as they are independent of free oxygen, the second, **Aërobic,** because they require it. The green microbes require light; most microbes live either in light or darkness, but are killed by direct exposure to sunlight. The conditions of heat are more complicated. Actual subjection of protoplasm to a heat very little under boiling point certainly kills all microbes; but some microbes, and the spores of most, can resist heat so well that even a considerably prolonged exposure to temperatures above boiling point does not kill them. In such cases, however, it is probable that the wall of the microbe or the spore prevents the protoplasm within it from actually reaching a high temperature. Freezing arrests the growth of all microbes, but even continued exposure to such a temperature does not kill them. Thus ice made from water containing microbes contains them in a condition only of arrested vitality; when the ice melts, the suspended organisms begin to multiply. Generally speaking microbes flourish best at a temperature between 30° and 40° Centigrade, but the most favourable temperature is different for different forms.

Microbes are associated with many of the processes of every-day life. The most obvious, and perhaps the most important is their association with **putrefaction**. If an organic substance—for instance, soup—be boiled for some time and exposed to the air, it slowly begins to putrefy. A scum forms on the top, and this can be seen to consist of many microbes embedded in a layer of jelly (zooglœa). The liquor becomes turbid and gives off an evil smell: examination of it shows that microbes abound. After a certain length of time it becomes clear again: green organisms appear in it and putrescence has ceased. On a large scale this process goes on everywhere in the world. Microbes serve to break down organic matter into inorganic; to clean up the *débris* of the organic world, and so to prepare the way for fresh cycles of life. On the other hand, if some of the boiling soup be placed in a vessel that has been itself boiled, and so freed from microbes, and if the mouth of the vessel be plugged with cotton wool (previously baked for some time to kill microbes), no putrefaction will occur, and no bacteria will be found in the fluid. Putrefaction occurs only when microbes get access to the substance; if any air that may reach the substance be filtered through cotton wool, the spores or microbes present in the air are kept behind, entangled in the meshes of the wool. But so omnipresent are spores, that the slightest fleck of dirt, the use of a dirty instrument, or exposure to the air in the act of pouring out the hot liquor, allows the entrance of spores or microbes and causes putrefaction.

Microbes are associated with many kinds of **fermentation**. Thus, some, like yeast, cause alcoholic fermentation; others turn milk sour by causing the formation of lactic acid; others cause the formation of acetic acid from alcohol—*i.e.*, "sour" wine by turning it into vinegar. Many that live in the soil perform useful functions. Thus one microbe aids the transformation of ammonia into nitrous acid : another turns nitrites into nitrates ; and thus these two prepare necessary food for plants by turning ammonia, which the roots of plants do not absorb, into nitrates, which they do absorb. Another set of microbes live in little colonies on the roots of some forest trees and of common pod-bearing plants like peas and beans and vetches. Such plants, by the aid of the colonies of bacteria, are able to make direct use of free nitrogen, whereas most plants cannot make use of it. Thus, in what farmers call green manuring, if a green crop of wheat or oats be ploughed into the soil, the decay of the plants adds no nitrogenous richness to the soil, for all the nitrogen in these plants has been taken by them from the soil. On the other hand, if a crop of green vetches or of beans be ploughed in, the soil is enriched in nitrogenous compounds, for beans and vetches, by the aid of the bacteria on their roots, have made use of the free nitrogen of the air

Many microbes are the cause of disease in man and animals. In some cases the multiplication of the particular microbe within the body causes mechanical injuries ; capillaries may be blocked up, cells and tissues may be broken down. In others, the microbes form some kind of poison which, carried through the body by the blood, arrests or disorders functions by action on the nervous system. It has been noticed that the poisons set free by such microbes are fatal to the microbes themselves, and, if death of the body affected does not occur in the interval, diseases due to microbe poisoning may run their course and then cease by the actual poisoning of the microbes themselves. An animal that has survived an attack of this kind is frequently **immune** to further attacks, and from this starting-point many attempts at preventive inoculation have been made. It has been found that if disease-producing microbes are cultivated for several generations in special substances, they are altered so that the microbes themselves or the poisons they give out, when introduced into the body of an animal, cause a change in the animal body not nearly so disturbing and dangerous as the changes produced by the uncultivated microbe, but yet equally efficacious in preventing subsequent attacks of the uncultivated microbe. Among the leading diseases associated with or caused by microbes are tubercle, tetanus, anthrax, diphtheria, cholera, typhoid. But the relation between microbes and diseases is now in itself a great branch of science, and continual additions to the list of cases are being made.

On the other hand, many microbes normally present in the body are harmless or useful. A large number present in the alimentary canal aid the process of digestion, while others are harmless parasites.

CHAPTER VIII

SINGLE-CELLED ANIMALS—PROTOZOA

ALTHOUGH most of the plants with which we are familiar consist of a multitude of cells specialised for different purposes and arranged in different ways, there are many plants, like *Protococcus* and the yeast plant, each of which consists of a single cell. So also with animals; all the larger animals consist of a large number of cells specialised for various purposes and arranged to form different tissues and organs. But there are very many animals grouped together by zoologists under the name **Protozoa**, in each of which a single cell may form the whole animal. These simple animals abound in nature; every drop of stagnant water contains many of them; they are to be found in pools and ditches, in lakes and rivers, on the bottom of the sea and on its surface, and in the slime and mud of the shore. If some fluid containing organic matter be exposed to the air, single-celled animals will appear in it almost as soon as bacteria, reaching it from the air in the same way as bacteria reach it. Many of them live as parasites in the bodies of animals or of plants. If the contents of the rectum of almost any animal that lives in water (as, for instance, a water-beetle or a frog) be examined under the microscope, many protozoa will be found. Other

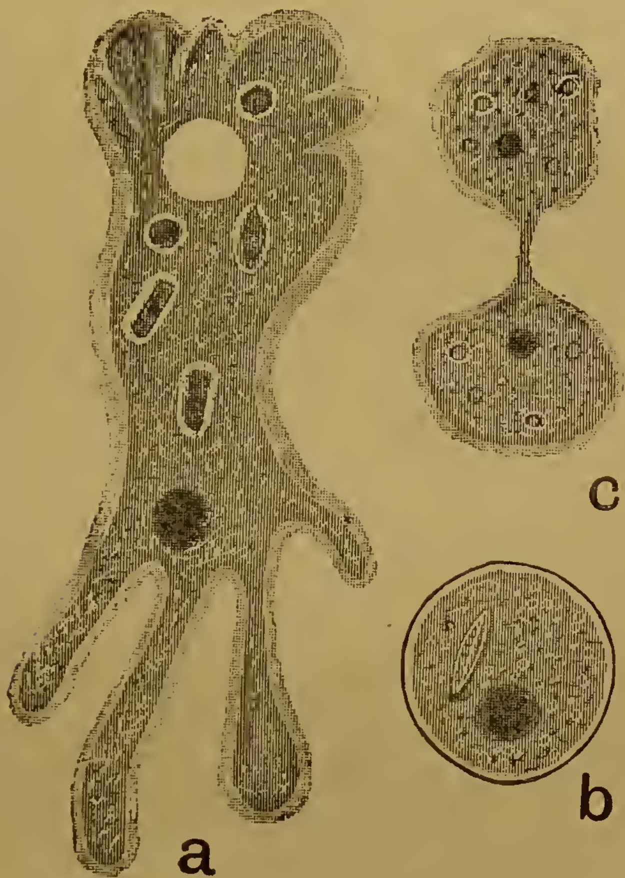

FIG. 27.—a. *Amœba proteus*, with retracted pseudopodia at one end near which is the contractile vacuole. At the other end are four protruded pseudopodia, and above them lies the nucleus. Embedded in the protoplasm are five food-vacuoles containing small ingested organisms. b. Encysted *amœba*. c. *Amœba* dividing by simple fission.

protozoa live in the body-cavities and deeper tissues of most animals and in man, sometimes harmlessly, sometimes causing diseases in their hosts.

One of the most abundant of the protozoa is that named **Amœba**. The largest Amœbæ are just visible to the naked eye, although even these are too small to be identified except under the microscope. The smallest of them are not much larger than bacteria. They are to be found both in fresh and salt water, while some of them are internal parasites of other animals. But they are obtained most easily from mud or slime at the sides or at the bottom of water containing organic matter. In a green-house, where flower-pots are allowed to stand in saucers, the slime collecting in the saucers is a favourite habitat of Amœba. So also is the slime round the sides of tanks used either as marine or as fresh-water aquaria. When one wishes to find Amœbæ in ordinary ditch- or pond-water, the water should be allowed to stand in a vessel until the mud has settled, and then small quantities removed by a pipette from the surface of the deposit of sediment should be examined under the microscope. They are not to be found floating through the bulk of the water, for Amœbæ are neither motionless, like the resting stages of Protococcus, nor do they swim actively through the water like its motile stages. They are creeping cells, which move slowly along some surface like the mud at the bottom of water or through thick slime. Even in the very small area of a drop of water between a glass slide and a cover-slip, they are usually motionless and inactive and difficult to see, until they have sunk to the surface of the slide or crawled out on the under surface of the cover-slip. They are also difficult to see (until the eye has become accustomed to their appearance) by reason of their transparency and absence of colour. They are simply little naked masses of protoplasm, without a limiting and defining cell-wall, and almost unceasingly changing their shape. It is by their movements that they first attract one's eye. Amœba has a thin external layer which is even more transparent than the central portion of the cell, which again appears granular and contains various foreign bodies, such as pieces of food which have been taken in. The clear outer layer contains none of these. As one watches it, one may see at some point in the animal the more central granular layer suddenly flow out, pushing before it but not rupturing the external layer, so that a long tongue or process called a **pseudopodium** protrudes from the surface of the animal. Sometimes several of these project from different parts, and none of them remain stationary for long. Thus the animal is constantly changing its shape. In this way, too, it creeps along; for the whole of the protoplasm may follow in the direction of one pseudopodium, as has been already described in the case of the amœboid corpuscles of the frog (p. 6). The movements of free-living Amœbæ, however, are much more rapid and lively than are those of amœboid cells. The pseudopodia may have different shapes. Sometimes, as is the case with the most common Amœbæ of salt water, these are excessively long and slender, stretching out to a distance two or three times the width of the mass of the animal. In the most common Amœbæ of fresh water the pseudopodia are long but quite broad and have rounded ends. In others the pseudopodia may be short, blunt, or pointed. In the cases mentioned the pseudopodia appear upon any portion of the surface of the cell. In other cases very few processes, generally only two, are formed, and these appear at two definite points opposite each other, so that this kind of Amœba has an elongate, recognisable shape. It is not to be supposed that any specimen of Amœba may present all these different forms of pseudopodia. Careful observation will show that in most cases they conform to one of the types mentioned. As in all cells, there is a **nucleus** in Amœba, but in different animals it has different appearances. Usually it is a rounded oval, with small, regular, darker masses or **nucleoli** within it. Sometimes it is round; sometimes there are a large number of small nuclei in place of one large nucleus.

Amœba is not the name of a single species or individual kind of animal. It is what is called the **generic** name of a number of different species which are all more closely allied to each other than to any other kind of animal. Thus the dog, wolf, jackal, fox, and the cat, lion, tiger, and leopard all are different *species* of animals. But the dog, wolf, jackal, and fox are all closely allied and similar in structure, while the cat, lion, tiger, and leopard are similarly related. In order to distinguish the animals and express these relations what is called the **binomial nomenclature** was invented. Thus the generic name of the dog and its allies is *Canis*, and a second or specific name is added to distinguish the species to which the animal belongs. The dog is *Canis familiaris*; the wolf, *Canis lupus*; the jackal, *Canis aureus*. The generic name of the cat is *Felis*. The wild cat is *Felis catus*. The domestic cat is probably a cross breed. The lion is *Felis leo*, the tiger, *Felis tigris*; the leopard, *Felis pardus*. *Amœba* is a generic name and there are many species of *Amœba*, no doubt more difficult to distinguish because of the smaller number of visible characters, but still different animals, like the dog, fox, and wolf. To a certain extent these species of *Amœba* can be distinguished by the shape of the nucleus, the form and appearance of the pseudopodia, and to an expert eye by the general appearance of the whole animal. But besides the visible characters the species are separated by many others. Thus a species that is accustomed to live in fresh water is killed by being placed in the sea water in which a sea-water species is living. An *amœba* of salt or fresh water taken into the alimentary canal of man would almost certainly be killed and would certainly not set up the diseases caused by the species that may be found there.

In certain cases two Amœbæ of the same species coming together go through what is called **conjugation**: the protoplasm of the two fuse together and the two animals live as one for a time. If Amœbæ of different species came together, either no result would follow or one would eat the other. By careful experiment, it has been found possible to accustom Amœbæ to unusual conditions of life, to keep fresh-water Amœbæ, for instance, in water to which salt has been gradually added. But we have no reason to suppose that experiment, however prolonged, could change a fresh-water species into one of the existing salt-water species, although it is possible that it might turn the fresh-water form into a new salt-water variety. It seems to be as true of the species of Amœbæ as of the species of all animals, that species are kinds of animals with distinct structure, properties, and habits, and that although it may be possible to change or modify the structure or properties or habits of a species by subjection to unusual conditions, it is not possible to turn one species into another existing species.

The most convenient Amœba to study is *Amœba proteus*, the largest found in fresh water. In this, the pseudopodia are long but wide and are usually rounded or even expanded at their ends. The nucleus is not easily seen unless the specimen has been killed and stained, but even in a living state it may be recognised as a rounded oval structure embedded in the granular protoplasm, darker in colour, and of more even texture. It can move freely in the protoplasm and shifts its position during the creeping movements of the animal. A large contractile vacuole is always present and its slow expansion and quick contraction can be studied with ease.

As Amœba moves about, it comes in contact with various little animals and plants living in the same mud or water. It may be observed **ingesting** these, taking them into its interior at any point. Sometimes two pseudopodia entrap the prey between them, and fusing together embed it in the common mass of the animal. When the prey is part of the filament of an alga like, for instance, Spirogyra, the Amœba engulfs a portion which remains attached to the rest of the plant. It is such small animals and plants that form the food of Amœba. The ingested prey may be seen to lie in the protoplasm surrounded by a small layer of fluid which consists partly of water unavoidably taken in with the food, but which also contains some digestive juice similar to gastric juice and secreted by the protoplasm. This little space containing digestive juice and food is known as a **food vacuole**, and several of them may be seen in one Amœba. The living material of the ingested animal or plant is acted upon by the digestive juice, and its proteids are turned into soluble material. The digestion of the food can be watched best when it is a green plant. First the chlorophyll is destroyed and all the soft part of the plant disappears, leaving behind only the cellulose wall and a few particles of indigestible *débris*. The nutritive juice thus formed gradually passes out of the vacuole and gets lost to sight in the minute spaces of the protoplasm. Finally, the indigestible remains are squeezed out of the Amœba at the nearest point.

Experiments show that Amœba requires either living protoplasm, in the form of the bodies of animals or plants, or dead proteid matter, like raw beef or white of egg, in order to live or grow. It cannot digest starch or fat, and, unlike a plant, is unable to build up proteid material from simple inorganic salts: nor, unlike the yeast plant, can it make use of ammonium tartrate as its nitrogenous supply. Like the yeast plant and green plants when sunlight is not acting upon their chlorophyll it requires a supply of oxygen. Mineral substances, which appear simply to be those entering into the composition of protoplasm, it obtains partly from the protoplasm of the organisms it eats and partly from the small quantities of salts which are present even in fresh water. For its life-history, then, Amœba requires small quantities of mineral matter, proteid, either in the form of living organisms, as is the natural condition, or supplied it artificially, water, which it gets directly from its surroundings, and oxygen which is dissolved in the water. The protoplasm or proteid is digested and absorbed and the nutritive material passes into the interstices of the protoplasm. The indigestible portion is excreted or turned out. The real waste matter of the Amœba, that which come, from the actual wear and tear of its protoplasm in the processes of life, is secreted into the contractile vacuole and then discharged as an excretion from that, just as nitrogenous waste is removed from the blood by the kidneys and discharged from the bladder to the exterior.

As a matter of direct observation it is not known how the carbonic acid, the result of the oxidising process of the living protoplasm, is removed, but probably it is discharged into the water just as the oxygen is taken up from the water.

It is to be noticed that all these processes of taking in, building up, and giving out, go to make up what is called the vital activity of protoplasm. In the complicated bodies of higher animals mechanical conditions may come into operation. Thus, for instance, the absorption of oxygen by the lungs and the discharge of carbonic acid may be aided, in accordance with the laws of diffusion of gases, by the difference between the low pressure of oxygen in the venous blood and the higher pressure in the atmospheric air in the alveoli of the lungs; while the excretion of carbonic acid may be aided by the fact that the blood in the lungs contains an abnormally large amount of that gas, while the air contains a very small amount. In such a condition of things the laws of the diffusion of gases may come into operation. But in the case of Amœba there is no arrangement of this kind, and it is important to remember that it is one of the properties of the protoplasm of Amœba, and in all probability of all protoplasm, to absorb oxygen and discharge carbonic acid independently of pressure and diffusion. So also with the discharge of the nitrogenous waste matter. In the body of man the separation from the blood in the kidneys of urea and of water may be aided by the mechanical conditions of the complicated structure of the kidneys. But in Amœba this secretion and discharge of waste matter goes on independently of specially adapted structures. It is one of the properties of the protoplasm of Amœba, and probably of all protoplasm, to excrete nitrogenous waste matter.

When Amœba has an abundant supply of food, the building up of new protoplasm goes on more rapidly than the process of breaking down, and the Amœba grows larger. As is the case with all cells, there is a limit of size beyond which an Amœba does not go. Instead of growing larger, or of ceasing to feed, **reproduction** takes place. It cannot, however, be said that reproduction is simply the direct result of the attainment of a certain size. The size at which it takes place is different in the case of different species of Amœba, and even varies in the case of individuals of the same species. In the case of many single-celled animals, although not in the case of Amœba, it has been shown that although the most abundant supply of food be given, and the other conditions be favourable to active growth, reproduction by division will not go on for an indefinite number of generations. After a time the individuals appear to become more languid and feeble and the greater number of them die. A few, however, undergo the process of **conjugation**. In the case of Spirogyra it will be remembered that in unfavourable conditions a kind of sexual reproduction took place. The protoplasm of two cells united to form a spore. In the case of some Protozoa after two cells have come together, the nuclear matter of each and the protoplasm of each unite, and the whole mass becomes enclosed in a firm cell-wall and breaks up into a set of spores. In other cases, after the two cells come together in the process of conjugation, a complicated interchange of nuclear matter and apparently of protoplasm goes on between the two, and ultimately the two separate again, and each takes up the usual method of reproduction by simple division. In Amœba the process of conjugation has been noticed, but the exact details of what occurs are not known. It is, however, clear that although reproduction by division is due in the first place to growth, this process will not occur to an indefinite extent in any individual case ; reproduction is not a simple effect of overgrowth. As in the case of excretion and respiration, we have to fall back on the statement that, as an observed fact it is a property of the mass of protoplasm known as a cell to divide.

The actual process of reproduction in Amœba begins with the nucleus. This becomes elongated ; a contraction appears in the middle, giving it a dumb-bell shape ; the contraction deepens until the elongated nucleus is separated into two nuclei. During the division of the nucleus the surrounding protoplasm also constricts, and ultimately the whole animal divides in two (Fig. 27. *c*). In this process there is no trace of any distinction between the two halves of the daughter Amœbæ. Both are exactly alike, and, except in size until they have grown, they are exactly like the parent cell.

One notable point in which the reproduction of Protozoa by simple division differs from the reproduction of higher animals must be noticed. A man, or a cat, or dog gives rise to sons and daughters and ultimately dies. In the case of Amœba, the sons and daughters are themselves the body of the parent ; the single Amœba as an individual disappears. As a mass of protoplasm it is not subject to death except as an accident. As we know only of reproduction by simple division in the case of Amœba and of many other Protozoa, those alive just now have descended, so far as we can infer, in a direct continuous chain of division from the first Amœbæ that ever lived.

There is one other occurrence in the life of Amœba which must be noticed. Occasionally, especially under unfavourable conditions, a thin skin or cell-wall forms round the Amœba. This is excreted by the protoplasm and is a substance of a horny nature. The pseudopodia are withdrawn, the animal assumes a spherical shape and the cell-wall, or **cyst**, becomes thick and nearly opaque (Fig. 27. *b*). After a period of quiescence the wall of the cyst ruptures, and the Amœba creeps out, leaving behind it the empty cyst. Except that it may serve as a means of protection against untoward influences, the meaning of this process of encystment is not known.

CHAPTER IX

CILIATED PROTOZOA

IN many Protozoa allied to Amœba the pseudopodia assume peculiar shapes. A single, long, tapering pseudopodium which is vibratile but cannot be withdrawn resembles very closely the two long cilia or flagella to be found in the motile stages of Protococcus. Sometimes the pseudopodia are branched at the tips. In others the tips are expanded into tiny knobs, which under the microscope give the appearance of minute pins inserted into the cell by their points, as is shown in Fig. 28. An occurrence of very great interest may be seen in a protozoon with tentacle-like pseudopodia by any one who cares to watch sufficiently long for its occurrence. The Protozoon in question is an acinetan called *Sphærophrya* (Fig. 28). It is common in fresh-water ponds in this country, and may be found if the method recommended on page 10 be followed. It is a small form, nearly circular, and possessing a large number of very long slender pseudopodia with knobs at their tips. These knobs consist of liquid tenacious protoplasm, probably with poisonous properties. By them small swimming Protozoa are captured, and in a captured animal, after a short struggle, the movements of life are paralysed, and, by the bending of the knobbed pseudopodium, the prey is gradually pulled into the cell-body and there engulfed. Here, then, is a case where, instead of a simple pseudopodium which may disappear and be reformed at any moment, there is a more elaborate structure specialised for a particular purpose. *Sphærophrya* may be seen to divide by simple transverse fission.

In Fig. 28. *a* this has occurred, and the two daughter cells are beginning to draw apart. The only difference to be noticed between the two is that one is rather smaller In Fig. 28. *b*, which was drawn from the specimens about fifteen minutes after Fig. 28. *a*, the smaller result of the division shows a more irregular shape, and its knobbed pseudopodia, at first of equal length to those of the larger animal, have become much shorter. At Fig. 28. *c*, drawn a few minutes later, the smaller organism has become much more elongated and nearly oval ; and a large and active contractile vacuole appears in it. Suddenly, as one watches it under the microscope, a most remarkable change

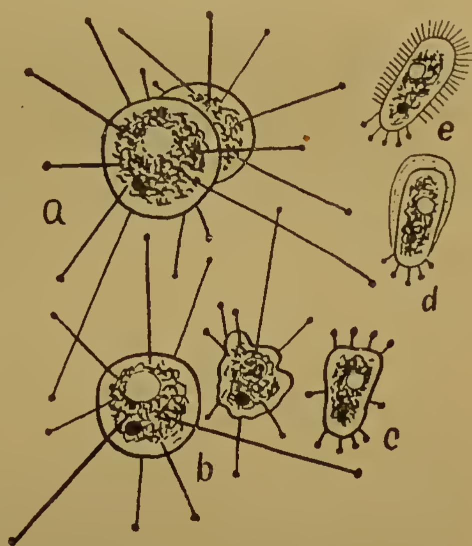

FIG. 28.—An Acinetan dividing. a. The two daughter cells are alike ; b. one cell becomes irregular in shape and the suckers are shorter ; c. the cell is elongating ; d. the suckers, except at one end, have broken down into a zone of protoplasm ; e. This zone has broken up into cilia, and the animal begins to swim.

occurs. The knobbed tentacles at one end of the oval break down into a faint transparent layer of protoplasm, as shown in Fig. 28. *d*, and almost as suddenly this layer of protoplasm breaks up into a number of delicate short waving lines of protoplasm. These are called **cilia**, little hairs, and by their rapid vibrations the oval animal, hitherto stationary, is propelled through the water at a pace which makes it difficult to keep it in the field of the microscope (Fig. 28. *e*). After a short period of vagrant life the animal settles down ; the cilia again disappear and knobbed pseudopodia take their place, while the nearly spherical form is assumed again. Cilia, then, in their simplest condition are protoplasmic structures to be regarded as specialised pseudopodia.

A large number of the most common Protozoa are characterised, among other features, by the possession of cilia. These have two chief uses : they may serve to propel the animal through the water, or, when the animal remains stationary, their vibrations may draw currents of water towards the animal itself, and in these currents are carried the small organisms which serve as food. Another feature in the ciliated Protozoa is that their protoplasm instead of being naked, as in Amœba, is protected by a delicate cell-wall. This, like the cyst of Amœba, is a horny material secreted by the protoplasm. A great advance in complexity of structure results. Amœba and other naked-walled Protozoa can take in food at any point of their surfaces. In the other forms, the cell-wall either prevents this or makes it difficult. And so in the ciliated Protozoa a small part of the surface is usually unprotected by cell-wall and serves as a **mouth** to take in food and an **anus** by which excreta are discharged. This soft part of the surface of the animal, no doubt for reasons of safety, is frequently sunk down until it comes to lie at the bottom of a funnel-like depression which may be called the **pharynx** or **gullet**. Round about this, special bands of cilia serve to sweep currents in towards the mouth, and the whole depression may be covered and protected by a movable part of the body of the animal which serves as a flap or lid to the pharynx. It is to be remembered that all this structure is within a single cell. The parts are not formed by the arrangement of many cells, like the mouth, gullet, and so forth, of higher organisms. Organisation, the formation of organs, although most familiar to us in the case of many-celled animals, exists in single-celled animals also. The capacity of becoming organised, then, is one of the properties of protoplasm.

Among common ciliated Protozoa are the bell-animalcules of the genus *Vorticella*. The various species of this are to be found almost everywhere, in fresh water or in sea water. They are small in size, but under the microscope they may be recognised at once by their habits and shape. Each consists of an oval or bell-shaped head attached to water-weed or pieces of stone, or even to the shells or bodies of small aquatic animals. The whole animal, which, although very complicated, is a single cell, is clad with a delicate cell-membrane. At what may be called the lower or attached end of this, the membrane is drawn out into a long, exceedingly delicate, hollow stalk by the extreme end of which it is anchored. Within this hollow stalk a darker protoplasmic thread runs from the protoplasm of the cell-body in a very loosely twisted spiral to the extreme end of the stalk. Under the higher powers of the microscope this axial thread of protoplasm is seen to be granular, and the granules are arranged in lines across the short diameter

FIG. 29.—Living Vorticella in the act of expanding ; the spiral stalk with central contractile thread is uncoiling ; the peristome has expanded and the cilia are in active motion ; under the raised edge of the disc a ciliated pharynx passes into the interior of the cell ; to the right of the pharynx the pulsating vacuole is seen as a clear spot ; looped in the protoplasm is the horse-shoe-shaped nucleus ; several food-vacuoles appear as dark spots.

of the thread, giving it a striated appearance. The slightest jar causes the stalk to contract, and the contraction consists in the loose spiral of the thread of protoplasm suddenly coiling into a very tightly rolled spiral, so that the stalk is shortened into a thick coiled cylinder not so long as the bell-shaped head, which is pulled down close to the point of support. The contraction is due, not to a change in the actual bulk of the protoplasm, but to a change in shape. So also in the muscles of higher animals the shortening of a muscle fibre is always accompanied by a change proportionate to the increase in the thickness of the fibre. The unrolling of the spiral, and the consequent protrusion of the Vorticella from its place of anchoring, takes place much more slowly.

In the contracted condition the head, or cell-body, of Vorticella is nearly globular. As the uncoiling proceeds, the globe slowly becomes bell-shaped. The circular edge of the bell mouth, which has been tucked into the bell cavity, first expands, and is seen to form a circular lip, of which the edge all round is slightly folded back. This is called the **peristome,** because it surrounds the **stoma**, or mouth. As the peristome expands, the edge of a circular disc lying in the mouth of the bell is pushed up, like the lid of a "Jack-in-the-box," and from between the pushed-up edge and the inner edge of the peristome one or two long, stout bristles are protruded. At the same time a circle of long cilia which are arranged round the edge of the disc begin to vibrate very rapidly and to cause a whirlpool in the water, by which any small floating objects are drawn inwards to the opening under the edge of the disc. This opening leads into a funnel-shaped depression, the **pharynx**, lined with vibratile cilia, and leading inwards to the centre of the cell. At the bottom of this depression a small area, not covered by cell-wall, serves as the actual mouth by which food-particles drawn into the pharynx by the action of the cilia are actually taken into the protoplasm. Another soft area at the side of the funnel serves as the anus by which the indigestible portions of the food are extruded. In the protoplasm near the anus is a large **contractile vacuole**, which one may see slowly expanding and rapidly discharging its contents into the pharynx, from which they escape to the exterior. In the protoplasm, also, many **food vacuoles**, like those of Amœba, may be seen at different places. Lastly, the **nucleus** can be seen as a very

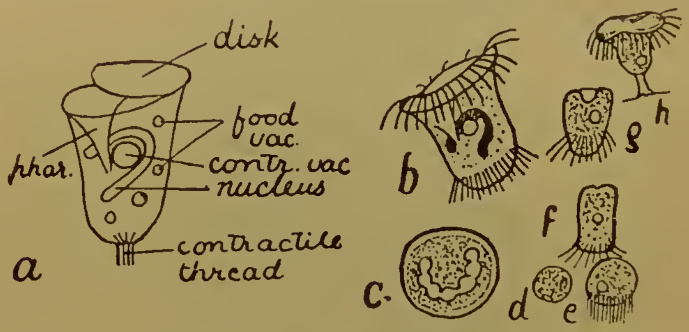

FIG. 30.—**a.** Diagram of *Vorticella*. **b.** Motile form. **c.** Encysted *Vorticella* with beaded nucleus. **d.** One of the spores into which **c** divides. **e–h.** Stages in the development of spore into adult form.

long and rather narrow granular mass, twisted into a horse-shoe shape, and, near it, a small micronucleus.

Notwithstanding the much greater complexity of this unicellular animal the processes of respiration, digestion, and excretion take place precisely as in Amœba. As it is fixed to a particular spot, and so can be kept under observation more easily, it is more easy to experiment with. If granules of carmine be placed in the water near it, the direction of the ciliary currents may be observed, and the precise spot at which the food material is taken into the protoplasm may be noted. It is possible also to study the motion of the cilia in detail. By the introduction into the water on the slide of a minute trace of dilute iodine—or better, of a drop of water into which tobacco smoke has been blown through a tube—the movements of the cilia may be made slower, although a slight overdose permanently arrests them. If a single cilium be watched, the movement may be seen to consist of a series of quick bendings in one direction, each bending being followed by slower recovery of the straight position. The cilia are themselves protoplasmic structures, and the bending and recovery are due to alternate contractions of the protoplasm on either side of the cilium. Ciliary motion, then, is a form of protoplasmic activity.

Reproduction in Vorticella is more complicated than in Amœba. First, reproduction by longitudinal fission occurs. The nucleus divides as in Amœba, and then division of the cell-body occurs. At first the two daughter cells remain attached to a common stalk, and in many close allies of Vorticella, "colonial forms," with a number of heads on the same stalk, may thus be formed. But in Vorticella, one part remains attached to the stalk, the other half grows barrel-shaped, and towards the lower end of the barrel a second ring of cilia develops (Fig. 30. *b*). Then the barrel-shaped Vorticella leaves the parent stalk, and propelled by the ring of cilia swims about actively for a time. Ultimately it settles down, and a stalk grows out by which it is anchored in a new locality, and it becomes indistinguishable from the parent organism or from its stationary twin. In this way the fixed Vorticella may spread from place to place, and those animals that settle down in positions favourable for food survive. Occasionally, however, it may be seen that a fixed form gives rise directly to the vagrant form by developing a posterior ring of cilia and breaking away from its stalk. This happens in circumstances where the water is evaporating, as, for instance, when a number of Vorticella are kept for a few hours under observation in a very small quantity of water.

In a second form of reproduction the Vorticella divides into a large and a small portion, the latter part appearing simply like a bud upon the larger. The small cell becomes an elongate, barrel-shaped, vagrant form, with a posterior ring of cilia, as in the case first mentioned, the only difference in appearance being that the vagrant buds are very small. Sometimes the Vorticella divides in two, and while one half remains attached to the stalk the other breaks up into several vagrant forms. Thus, when this kind of division has been occurring, there result a number of fixed forms and a number of small wandering forms. Between these conjugation may occur. A vagrant form comes up to one of the fixed forms to which it has wandered, and the protoplasm of the two completely fuses, or, at the least, complicated nuclear interchanges take place. After the process, reproduction by fission occurs more vigorously in the fixed form. The interest of this process of conjugation is that it foreshadows the sexual reproduction of higher animals. The large fixed form represents the egg-cell of the female, which is usually large and stationary; while the small, actively swimming form corresponds to the spermatozoon, which is a small, freely moving cell that seeks out and fuses with the egg-cell.

A third method of reproduction is preceded by encystment. A Vorticella becomes detached from its stalk, and secretes a thick cell-wall (Fig. 30. *c*). Within this the nucleus and the protoplasm break up into a number of little spores, in each of which there is a portion of the nucleus and some protoplasm. A cell-wall forms round each spore, and ultimately the cyst ruptures, liberating the spores. It is by these that Vorticella most easily gets carried from place to place, by the wind or by other agencies. The thick wall of the spore protects it against untoward influences. When the spore reaches a place favourable to development, its wall ruptures and the protoplasm creeps out as a little naked, partly amœboid, mass of protoplasm. This rapidly becomes elongated, and develops a ring of cilia (Fig. 30. *d* to *h*). It swims about actively, and finally settles down as the adult form, with stalk, pharynx, peristome, disc, and so forth. This foreshadows another feature of the reproduction of higher animals. The first stage in the life of the young of a worm, or a frog, or a man is very unlike the adult stage. It is a simple single cell, which only after a long and complicated series of changes becomes like the adult. Sometimes, as in man, all these changes go on within the body of the mother ; sometimes, as in the frog, some of the stages swim actively about as tadpoles, get their own food, and live exactly as complete animals while they are finishing their development. But in the cases of higher animals the building up of the adult form takes place by the multiplication of cells. The animal begins as a single cell : the adult is formed almost of innumerable cells. In the case of Vorticella the adult animal and each stage in its growth is to be regarded as a single cell. The development of the animal consists in the organisation and specialisation of its protoplasm.

CHAPTER X

THE DIFFERENCE BETWEEN ANIMALS AND PLANTS

WE have now passed in review a sufficient number of the lower forms of life to understand the differences between plants and animals. It is only by a consideration of these low forms that we can arrive at an exact idea of the distinction between the animal and vegetable kingdoms, because most of the distinctions with which we are familiar in the higher forms do not hold when we try to trace them back to the lower. For instance, it is easy to distinguish between a cow and a cabbage : the animal is an actively moving form ; the plant remains fixed in the soil. But some lower forms of animals, such as Vorticella, are usually fixed to one spot, while many of the lower plants, like Protococcus, have freely swimming motile phases. The cow has a compact solid shape with the chief organs embedded in the central mass of the body. It has a mouth and a stomach, a heart and blood, lungs and a nervous system, and internal generative organs. In the cabbage, the organs are not aggregated into a solid mass, but appear as thin, diverging leaves and flowers and roots. The cabbage takes in food and air by roots and leaves, it has no nervous system and no blood. But all these distinctions disappear when we come to distinguish between Protococcus and Amœba. If there is any notable difference in shape the Protococcus is the more compact, the Amœba more branched and divergent. Neither have lungs nor leaves, nervous system, stomach, nor heart. The cow may be almost any colour; the prevailing colour of the cabbage is green on account of the chlorophyll of the leaves; but many plants, like the yeast plant, and most bacteria, have no chlorophyll, and are therefore devoid of the familiar green tint of plants. Cows, like all animals, take in oxygen and give out carbonic acid. Cabbages, like all green plants, in sunlight take in carbonic acid and discharge oxygen: but we have learned that it is the property of all living protoplasm to take in oxygen and discharge carbonic acid, and, in the case of green plants, that this process is merely obscured, during the hours of sunlight, by the opposite process, due to the agency of chlorophyll. Even the cabbage at night takes in oxygen and gives out carbonic acid, while many plants, like the yeast plant and most bacteria, always need oxygen and, like animals, discharge carbonic acid.

It will be convenient to sum up the general distinctions between animals and plants before we attempt to follow them out in the lowest forms. The usual shape of plants is branched and irregular; their tissues grow chiefly by extension in lines and sheets. The usual shape of animals is compact and solid: their tissues grow as solid organs, forming rounded, bulky masses. The shape of an animal is therefore more or less definite and characteristic; the shape of a plant is quite irregular and capable of extension almost in any direction. The plant, as a whole, is usually stationary. Its organs, like root-hairs, or leaves or tendrils may have limited powers of movement, but the plant as a whole remains stationary. The animal body, on the other hand, in the vast majority of cases moves as a whole; it is active and muscular. The whole surface of a plant exposed to the air forms the organ of respiration, and from the arrangement of the tissues in flat, thin sheets and layers, the process of respiration without special organs is rendered easy. On the other hand, the internal tissues of animals are so far removed from the outer air that special organs of circulation and respiration are present, except in the simplest forms.

A plant takes in its food in the form of gases or solids in solution, by its leaves and roots. An animal takes its food in solid form by a mouth, and prepares it for absorption in a stomach. All animals require nitrogenous food in the form of proteid matter, and all animals take in oxygen and discharge carbonic acid. All green plants are able to build up starch from water and the carbonic acid of the air; with this supply of starch they are able to build up proteid although nitrogen is supplied to them only in simple salts like nitrates. On the other hand, a few green plants, like the insect-eating plants, are able, in addition, to digest and absorb proteid matter, although in their case the digestion of the proteid takes place outside the plant body by means of digestive juices poured out. The fungi, being plants devoid of chlorophyll, absorb oxygen, and liberate carbonic acid. Like animals also, they are unable to build up starch from water and carbonic acid, and if proteid be supplied them, they are able to absorb and digest it. But if starch or sugar be supplied them they are able to build up proteid from a nitrogenous salt like ammonium tartrate, a piece of chemical elaboration beyond the power of any animal.

Lastly, the cells of all the higher plants have rigid cell-walls composed of cellulose or of some simple modification of cellulose. The cells of all the higher animals are, in the vast majority of cases, surrounded only by thin, elastic and delicate cell-walls, and these are never composed of cellulose nor of any modification of cellulose.

We shall find it is easy to distinguish between the simple animals and plants we have been describing. Protococcus, Spirogyra, the yeast plant, and bacteria are plants: they have cell-walls of cellulose, which are rigid and comparatively inelastic; none of them have anything that can be compared to a mouth or stomach. Their food is absorbed as gases, and as solids dissolved in water. The two green plants build up their own starch from carbonic acid and water, and with the addition of nitrates can form for themselves the proteids of their protoplasm. The yeast plant and most of the bacteria cannot manufacture starch. When proteid matter is supplied them they will digest it and flourish; but they will also live and grow in a solution like Pasteur's fluid, which contains no proteid but nitrogen in the form of ammonium tartrate.

Amœba and Vorticella are animals: Amœba has no cell-wall in the normal condition: Vorticella has a thin cell-wall: but that, like the cyst of Amœba, is composed not of cellulose, but of chitin, a nitrogenous substance.

Neither Amœba nor Vorticella can manufacture starch nor build up proteid from simple salts, nor can they live in Pasteur's fluid. As food, they require actual proteid matter, preferably in the form of the living bodies of other organisms. These they take in as solid substances through a temporary or permanent aperture in the protoplasm, and digest in a food vacuole which forms round the food particles in the protoplasm. Another distinction is obvious in their cases. They get rid of nitrogenous waste by a special structure, the contractile vacuole. The plants have not this structure, and, in the case of these simple forms, it is not known how they get rid of their nitrogenous waste.

Although clear in the cases before us, the distinctions between plants and animals are not applicable in all cases of unicellular organisms. Some, for instance, have a cellulose cell-wall and chlorophyll, and so can live like green plants. But they also have a contractile vacuole and a mouth and pharynx, and, like Amœba, can ingest animal food. Others have no cell-wall, and have pseudopodia-like processes, and ingest solid food. But when they encyst, the wall of the cyst is cellulose, and the spores within the cyst have also cellulose walls.

No complete separation exists between the two kingdoms. It is most probable that animals and plants have a common origin and that some of the lower existing forms of life retain characters that afterwards became the marks of separate kingdoms.

CHAPTER XI

CELL-STRUCTURE AND CELL-DIVISION

WE have found that the simplest organisms, whether they belong to the animal kingdom or to the plant kingdom, consist of single cells. The bodies of all higher animals and plants are made up of many cells which are the result of cell-growth and cell division. In a sense, then, cells are the **units,** the living bricks out of which the animal and plant body are built up. We have seen, however, that, as in Amœba and Vorticella and Protococcus, very many different structures, which one may call organs, are present within the cell, and that different cells assume very different shapes and appearances and have very different properties. In the body of the plant we saw how the different tissues were made up of cells specialised for different purposes. So also in the animal body each tissue and organ has cells of special structure and with special functions. In Fig. 31 there are represented three of the many types of animal cells taken from a frog. At *a* is an epithelial cell taken from the roof of the mouth. The surface of the cell that is exposed to the cavity of the mouth is covered by cilia, which serve to sweep currents of water and mucus along the mouth from the throat. At *b* is a cell from the wall of the intestine drawn during a period of activity ; the end turned towards the cavity of the gut has pseudopodia by which food particles are ingested from the intestine ; some of these appear within the protoplasm. At *c* is an unstriated muscle cell from the bladder.

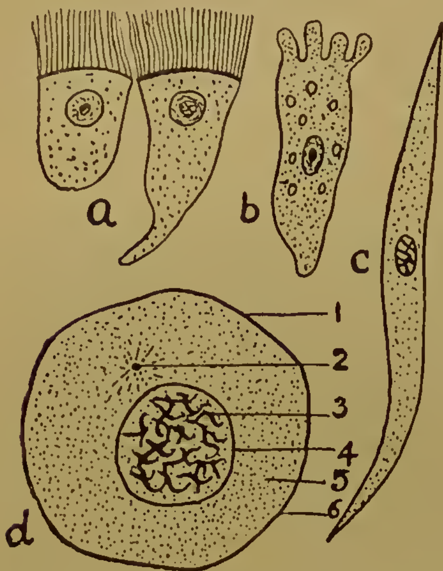

FIG. 31.—a. Two ciliated cells from roof of mouth of frog. b. Cell from wall of frog's intestine with food vacuoles and pseudopodia. c. Unstriped muscle cell from bladder of frog. d. Diagram of cell.—1. Wall. 2. Centrosome. 3. Chromatin fibres of nucleus. 4. Nuclear wall. 5. Protoplasm of cell-body. 6. Cell-wall.

Now these cells are typical of the kind of cell-specialisation which occurs. Each of them is modified and adapted to serve the animal, the cell-community of which it forms a part, in some particular direction. But in addition each performs all the functions of protoplasm on its own account. Each takes in oxygen and discharges carbonic acid, takes in food materials and discharges nitrogenous waste ; each grows when there is a balance of income from food over expenditure, and at least in the earlier period of its life, though seldom after it is specialised, each is capable of reproduction by simple division.

Overlooking the peculiarities of the different kinds of cells, it is necessary that a clear idea of the structure of every cell should be attained (Fig. 31. *d*). The protoplasm of the cell consists of two distinguishable parts.

There is what appears under the higher powers of the microscope a network or mesh-work extending all through the body of the cell. This is so exceedingly fine that the meshes convey the appearance of granules or fibres of more solid material (*see* Figs. 3 and 4), but there is reason to believe that it consists not of a net-work of more solid material, but of quite fluid material, forming the walls of the bubbles of a very delicate foam. Occupying the bubbles, or, as it is more generally described, bathing the meshes of the net-work, is a fluid juice containing probably the dissolved nutritive materials and the waste products of the protoplasmic activity. The cell-wall, when present, consists in the first place of more regularly arranged bubbles of the foam or meshes of the net-work, but this usually is strengthened by deposits of a secretion formed by the protoplasm of the cell. Within the cell lies the nucleus, composed of a net-work and a fluid bathing the net-work, similar in appearance and probably actually continuous with the net-work of the cell. The nucleus is surrounded usually by a delicate membrane, which, like the cell-wall in its simplest form, is merely a specialised part of the net-work. All these parts of the cell absorb stains or dyes rather feebly, and, when a stained cell is placed in a solution containing a solvent of the stain, the greater part of the colouring is removed. But, as we have seen already, there is within the nucleus another substance, a substance which absorbs staining materials with greater avidity, and which combines with the stains so firmly that when placed in a solvent very little is given up. This part of the nucleus, on account of this property, is named **chromatin**, and most are agreed that the chromatin is the part of the nucleus which is the bearer of its special properties. In most stained nuclei these chromatic elements appear as little separate granules or pieces very much larger than the granules of the cell-protoplasm. But occasionally it happens that the nuclear matter becomes broken up into a large number of very small parts which are no longer easily seen, and which, instead of remaining in a special nuclear region, become scattered through the whole of the cell. On the other hand, in many cells and in the great majority of cells before cell-division takes place, the nuclear matter appears to increase in bulk and may be seen to consist of a number of curved rods or loops named **chromosomes.** These chromosomes vary in number from two upwards, but it is probable that there is a specific number in all the cells of each organism.

In addition to the chromosomes, there is present in the nucleus of many cells a large spot, that in the case of egg-cells has been called the germinal spot. It is composed of clearer material, and though its function has not been made out with certainty, it has been seen to contract and expand slowly, each set of movements occupying several hours. It is therefore supposed by some to be a special pulsating vacuole for the nucleus, an excretory organ usually inactive, but coming into use when the cell is going through active changes like the changes of division.

Lastly, there has been shown to be present in some cells during their inactive condition, and in very many cells while they are undergoing a complicated process of division, a very small body composed of a material that stains only when special methods are applied to it. This is termed the **centrosome** (Fig. 31. *d* 2) because in the process of division it is the central body of a small circular area named the **directive sphere**, formed by the protoplasmic granules arranging themselves like radiating beams round the centrosome. It has been suggested that this is present in every cell, but that, owing to its minute size and the difficulty of staining, it can seldom be seen until, in the process of division, the rays of granules arrange themselves round it.

It is by the multiplication of cells that the development of an animal from the egg and its subsequent growth take place. Cell-multiplication is always the result of cell-division There is no case known in which an animal or a plant cell comes into existence except as the product of an already existing cell. This division takes place in two ways. In the simpler case, the nucleus may become constricted, and by fission divide in two portions, around each of which half the protoplasm of the cell becomes arranged (Fig. 27. *c*). Not long ago this was thought to be the usual method of division, at least in the tissues of animals. But recent observation shows that it is comparatively rare, and occurs in a few special cases of rapid division and in some abnormal growths where the tissues are diseased. The prevailing method is much more elaborate. The nucleus goes through a remarkable and regular series of changes, the result of which is that an exceedingly minute sub-division of the chromatin occurs, and that each daughter cell gets, so to speak, a fairer half of it, than in the rough-and-ready method of simple transverse division. This method of division is termed **mitosis**, or **karyokinesis**, and in general outline the process is similar in the cell-divisions of animals and plants, whether in tissue cells or in embryonic cells.

Although in the last few years a very large number of investigators have been observing and describing cases of karyokinesis, there is still variance among them as to the exact order of the events, and especially in their views of the relations these events bear to each other. The outline of the process is this. The centrosome divides in two; round each half radiating granules appear and form two sun-shaped directive spheres, which move to opposite poles of the cell. The nuclear chromatin separates into a definite number of chromosomes, and the nuclear membrane disappears. In the protoplasm between the two directive spheres, a spindle-shaped arrangement of colourless fibres separate from each other at the equator of the cell and converging to each centrosome, appears. The curved chromosomes become arranged in a ring in the middle of the spindle, each chromosome, so to speak, threaded upon a filament of the spindle by its central part, while its two free ends are bent outwards sharply. Then each chromosome splits in two along its length, and the halves move along the threads of the spindle, in opposite directions, to the centrosomes at the poles. When this separation of the chromosomes has occurred the protoplasm of the whole cell begins to divide. Sometimes this occurs, as in simple cell-division, by a constriction of the cell-wall round the equator until the cell is gradually pinched in two, each portion containing a centrosome and the halves of the chromosomes which have moved up the spindle. More often perhaps, and certainly more often in plants, the division of the cell-body occurs through the formation of a **cell-plate**. This is a plate of granular protoplasm which appears in the equator of the cell and runs through the centre of the spindle after the chromosome halves have begun to move towards the new poles. The splitting between the cells occurs by a splitting of this plate, or, as in the case of many plant tissues, the cell-plate may remain as the common cell-wall separating the two newly formed cells. While the splitting of the cell-body is going on in one of these ways, the chromosome halves at either pole approach more closely together, and, losing their definite outlines, become exactly like the nuclear matter of the cell before it began to divide. At the same time the colourless spindle fibres disappear and a wall forms round each of the two new nuclei. Last of all, the rays of granules round the centrosome of each daughter cell become faint and disappear. In some cases the centrosome itself remains visible, but while several observers maintain that it too disappears and is re-formed again from the nucleus when the new cell is ready itself to divide, others insist that it remains in the cell to start the new division.

It is to be noticed that the precise order in which these complicated events happen is not yet known with certainty, nor, indeed, whether the order is always the same. At one time it was thought that cell-division began with the division of the protoplasm, and that the nucleus merely followed the division of the whole. A later and more generally received view was that the nucleus started the process, and that the comparatively inert protoplasm merely followed the division of the nucleus. Since the division of the centrosome has been noticed, many observations suggest that this may be the organ of the cell which starts and directs division. But at present we

FIG. 32.—Diagram of cell-division by *Karyokinesis*. For explanation see text.

must rest content with knowledge of the general outlines of karyokinesis and await further investigation before deciding definitely upon any explanatory theory of what happens.

In Fig. 32 are represented the appearances of the nucleus at the various stages of karyokinesis. In I. the nucleus of the cell in its resting condition is shown. The chromatin is not separated into chromosomes, but appears as a coiled band, coloured black in the drawing. The band of chromatin then acquires a sharper contour due to the absorption of material from the plasm of the nucleus. In II. it has divided into a definite number of chromosomes, eight in this case. In III. each of the chromosomes has split longitudinally, so that now there are sixteen, arranged in pairs. At this period the nuclear membrane disappears, and the centrosome, although it may have been present before, comes into evidence. In IV. it is to be noticed first, that the nuclear membrane is broken; next that the pairs of chromosomes have taken up a regularly arranged position round the nucleus, with the free ends projecting outwards and the sharply bent central portions turned towards the centre of the cell. The centrosome (*c*) has divided in two (*c.c*) and, round each, radiating lines of granules appear, while between them a set of delicate straight threads are visible. The two centrosomes separate, and move to opposite poles of the cell while the threads between them elongate to form a regular spindle of colourless fibres. In the first set of figures we have been looking down on the nucleus from one of the poles to which a centrosome afterwards goes. In the other figures, we are looking from the side so that both poles are visible, and for the sake of simplicity the nucleus is represented as not transparent and as showing therefore only four pairs of chromosomes. In V. the centrosomes with their radiating lines of granules may now be called **directive spheres** ; they have moved to the two poles, and between them the spindle stretches. Projecting out from its equator are the four visible pairs of chromosomes ; the other four would lie similarly disposed on the other side of the figure. In VI. a chromosome of each pair is moving, as if it were being pulled up by the point, towards the centrosome at the pole. In VII. this has gone on so far that the individuals of each pair of chromosomes are quite separate. At this stage the division of the cell body, which is not represented in the drawings, begins, and the other structures begin to dwindle. In VIII. the chromosomes have reached the poles ; immediately afterwards the centrosomes and the spindle begin to disappear. In IX. these have gone, the chromosomes at each end are assuming the resting position, the nuclear wall is re-formed and is growing in between the two nuclei.

In most cases karyokinesis takes place in some such way as has just been described. Sometimes, however, the chromosomes do not divide in two, but one-half of the number moves to each pole. This may be called a **reducing division**, for if the original cell contained eight chromosomes, each daughter cell would contain only four ; whereas in the ordinary method as each chromosome divides in two, there are the same number in each daughter cell as there were in the cell before division.

One further point must be noticed. There are two classes of cell-division which must be distinguished by their results. When a tissue-cell divides, the results of the division are similar in appearance and function, each daughter cell being a tissue-cell exactly like the original parent cell. But in the development of an animal from the egg to the adult, as the tissues arise and separate off from each other, cell-divisions must occur in which the daughter cells do not become alike. However, so far as observation goes, there are not two methods of karyokinesis to account for this. If we judge merely by the nature of the process of cell-division that occurs while the animal body is being built up, *every cell, however different its structure and function come to be, receives what is to all appearance an equal and similar share of nuclear matter.*

CHAPTER XII

HYDRA

THE whole animal kingdom is divided into two great groups. The first of these is called the **Protozoa.** To it belong *Amœba* and *Vorticella* and all animals the bodies of which consist of a single cell. Occasionally among Protozoa, when reproduction takes place the new individuals do not separate from each other, but build up a **colonial form.** Such colonies of Protozoa may consist of a definite number of individuals: the whole colony may have a definite shape and in some few cases even all the individuals may not be exactly alike. But it never happens that the individual cells of a colony are arranged and specialised so as to form tissues and organs. All animals with bodies composed of cells arranged in definite layers and tissues which serve a special purpose in the economy of the whole animal, belong to the second and higher division of the animal kingdom and are called **Metazoa.** After the examination of one metazoon we shall extend and make more definite our idea of the nature of this group and of its points of contrast with the Protozoa.

The first metazoon that we shall examine is a small fresh-water animal called *Hydra*. Three species of it are not uncommon in the ponds and ditches of this country.

The largest specimens are, when fully extended, about three-quarters of an inch long; the smallest are easily visible to the naked eye. *Hydra viridis*, the green hydra, owes its colour to the presence of a large number of chlorophyll bodies in the inner layer of its body-wall. *Hydra fusca* is brown or yellow and *Hydra vulgaris* is nearly colourless. Apart from these colour differences the species are very similar, and any one will serve equally for examination. The specimens should be examined in the living condition, in a watch-glass containing water placed under the low power of a microscope. They consist of a cylindrical body attached to a piece of weed or to the side of the glass at one end. At the other end there is a circle of from six to ten long slender thread-like processes (Fig. 33). These are the **tentacles**, and they surround a small rounded elevation called the **hypostome**, at the free end of the cylindrical body, with a circular opening, **the mouth** at its summit. The whole body is exceedingly contractile. A slight touch with a needle will make a fully extended specimen contract almost at once to a little lump with the tentacles as thick knobs. By careful manipulation with needles or with a camel's

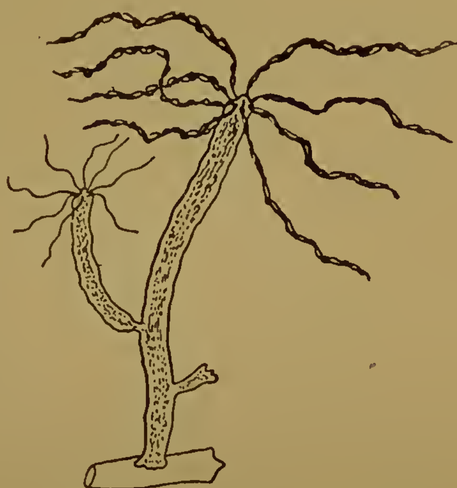

FIG. 33.—*Hydra vulgaris* in expanded condition; to the left is a young Hydra which has budded out from the larger specimen; to the right is a young bud.

hair brush, a specimen may be detached from its support. When it has recovered from the shock, it may be seen creeping along the bottom of the glass supported by its tentacles and carrying uppermost the **pedal disc** by which it was attached. Or it may creep by a series of looping movements, fixing itself by the pedal disc and stretching out the body so that the tentacles may attach themselves to a point some distance off, when the pedal disc loosens its hold and by contraction of the body is pulled to a fresh place for attachment, nearer the tentacles. Such movements are, however, of infrequent occurrence if the Hydra be undisturbed.

The water in which Hydra is found contains a number of small water fleas, and if some of these be placed in the watch-glass with it, before long one of them is certain to swim up against a tentacle. When this happens the motions of the flea are suddenly arrested : it has been not only caught but paralysed by some poison, and the Hydra, by bending the tentacle, draws it in towards the mouth and, sometimes with the aid of other tentacles, pushes it through the mouth into the central cavity. If Hydra be watched for some time, it may be seen to discharge from the mouth parts of the shell and other *débris*, the indigestible remains of similar fleas it has captured before. Thus the mouth serves also as an anus.

To study Hydra more fully, a single specimen should be removed to a slide in a small drop of water and covered with a glass-slip. Care should be taken not to let the slip drop too suddenly upon the animal as its delicate structure is easily broken up and destroyed. If the Hydra is not sufficiently compressed, some of the water may be removed by a piece of blotting paper applied between the edge of the cover-slip and the glass. When this has been done, observation with a higher power is possible. If the specimen be a green or a brown Hydra, it will be at once apparent that the body and the tentacles are composed of two layers. The outer layer is thinner and is quite colourless and transparent : the inner layer is deeply coloured by small granules, which in the case of the green Hydra are chlorophyll-containing bodies, and in the brown Hydra are granules coloured by a substance closely allied to chlorophyll. The central region of the body is a cylindrical cavity, and into this cavity, which is called the **enteron,** the mouth opens. In a living specimen the enteron appears as a darker region in which occasionally the bodies of captured water fleas may be seen. Each tentacle is hollow, but, in the living condition, it is almost impossible to see either the hollow or its opening to the enteron. In this condition it is easy to see that the outer surface of the tentacles is studded with little knobs. Here and there upon the knobs delicate projecting bristles may be seen, and if the Hydra has been irritated, exceedingly long pointed threads may be seen protruding. These threads are the poisoned lassoes by which Hydra catches and paralyses its prey. They are too delicate to pierce the human skin : but in some tropical sea-anemones and in jelly-fish of our own coasts such nettle-cells or **nematocysts** are present, and are strong enough to cause considerable pain, and sometimes poisonous enough to produce disagreeable effects if the naked skin of man come in contact with them. In Hydra the nettle cells are most numerous on the tentacles, but they occur also on the whole outer surface of the body. By focussing carefully they may be seen as small oval bodies, rather more pointed at the outer end and of a greenish yellow colour. Some of them lie close to the surface, and in these a small bristle, the **trigger-hair**, or cnidocil, protrudes beyond the surface of the animal. When this is touched by an external object, the lasso is shot out with great force. Before it has been discharged it lies coiled up within the nematocyst, and with an ordinary student's microscope at least the beginning of the coil may be seen. Fig. 34 represent very greatly magnified views of nematocysts isolated by pressure upon the cover-slip from the general surface of the body. An undischarged cell consists of a large rounded cell with protoplasm, a nucleus, and the protruding trigger-hair. Embedded in the protoplasm is the lasso. It consists of an elongated tough sac, one end of which is tucked into the larger end, like the finger of a glove turned outside in. The point of this infolded part is continued into a long, very delicate thread, which also is hollow. The whole space between the wall of the sac and the inturned part and the thread is occupied by a fluid under considerable pressure. When any additional pressure from the outside is brought to bear on the sac the apparatus suddenly goes off: the inturned part of the sac is first turned, or forced out, and then the long thread follows it, both being turned inside out in the process. The

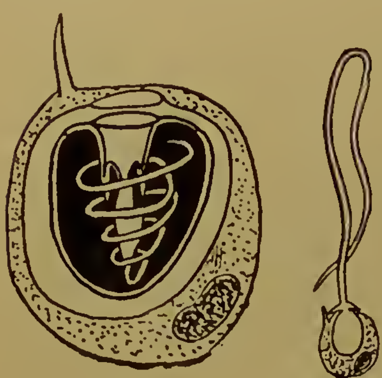

FIG. 34.—To the left is an enlarged diagrammatic view of an undischarged Nematocyst embedded in a nucleated cell. To the right is a discharged nematocyst.

second drawing shows a nematocyst shot out in this way. It has barbs at the root of the thread, an addition that is not present in all the nematocysts of hydra. A thread-cell once discharged cannot be used again. There are, therefore, a considerable crop of them always growing, and smaller partly-formed thread-cells may be seen in the inner part of the outer layer of the body. Processes from the nerve-cells have been traced into the protoplasm surrounding the lasso. The discharge of the lasso is caused by contraction of this protoplasm under the influence of a nervous excitation.

Among the specimens of Hydra collected at any time, some are likely to exhibit the results of multiplication by budding. In summer, while food is abundant and the weather warm, tiny hollow buds grow out from any region of the wall. The hollow of the buds is continuous with the enteron at first, although when the bud has grown longer this connection ceases. At the other end of the bud a mouth-opening appears and the circle of tentacles grows out (Fig. 33). Sometimes on the same hydra several buds may be seen, and even on these buds other buds may grow out, so that the whole forms a branching, compound animal made up of many individuals. Each of these, however, is practically a separate animal, and may break off or be removed artificially and live an independent life.

If the specimens be collected from ponds towards the end of summer, or if they be kept in captivity and starved for a few days, sexual reproduction occurs. In some individuals, on the body-wall near the base of the tentacles one or two small lumps appear. These are the **testes**, or male reproductive organs, and from them the **sperma-**

tozoa, or male sexual cells, are shed into the water. The same specimen of Hydra may produce the female sexual organ, but this hardly ever is to be seen on a Hydra at the same time as it produces the testes. As we know from observation of higher animals, one of the advantages of sexual reproduction is that the progeny are more hardy when the parents are not closely related. In Hydra and in other animals in which the same individual produces both male and female organs, the benefits of crossing would probably be missed if the female cell was ripe at the same time as male cells were being discharged near it from the same animal, and in correspondence with this it is seldom the case that one individual has the organs of both sexes at the same time.

The female organ or **ovary** of Hydra is always single, and is produced from the body-wall much lower down than the testes (Fig. 36). As a rule it contains only one egg, and is a large and conspicuous organ. The ovary at first consists of a mass of tiny cells. But one of these sends out pseudopodia among the rest, and gradually eats them up until it becomes very large. In this condition it appears like a huge amœba (Fig. 35), and contains embedded in the protoplasm a number of small yolk granules, which are reserve stores of proteid matter formed by its protoplasm. When fully grown the pseudopodia are withdrawn, and the egg-cell is spherical. As it has been eating up the small cells which lay around it, a part of its surface is bare and protrudes beyond the surface of the hydra. The male cells, or spermatozoa, which were discharged into the water, each consist of a nucleus and a small body of protoplasm, the most of which projects behind the nucleus as a long tail.

By the vibrations of these tails the spermatozoa are driven through the water. If one of them reaches the exposed surface of the egg on a Hydra it conjugates with that. The tail drops off, while the head, or nucleus, and a small fragment of protoplasm enters the egg-cell. The incoming spermatozoon-nucleus then fuses with the nucleus of the egg-cell and impregnation is complete. Soon afterwards the impregnated egg-cell begins to divide. From the resulting cells a cap or wall of cells, each with thick cell-walls, is formed. The egg so protected falls out of the Hydra, and sinks to the mud at the bottom of the pool. In this condition it remains throughout winter. In spring, when the water is warmer, it develops into a new Hydra in a way that will occupy our attention later on.

FIG. 35.—Ovum of *Hydra* with pseudopodia, nucleus, and yolk-spheres; the latter appearing as white spots. Below is a group of Spermatozoa.

Further study of Hydra is best made by the examination of excessively thin slices. As the preparation of these is a matter requiring great practice, the elementary student should content himself with the study of sections already prepared. Of these there should be examined a longitudinal section (Fig. 36) and a transverse section more highly magnified and taken through the cylindrical body (Fig. 37). The longitudinal section is a thin slice cut lengthwise out of the centre of the whole animal. It passes through two tentacles, through the hypostome and mouth, and through the enteron and the body-wall. It may be seen at once that the whole animal consists of a hollow sac surrounded by two layers of cells. Of these the outer layer, or ectoderm, is thinner, and in its cells

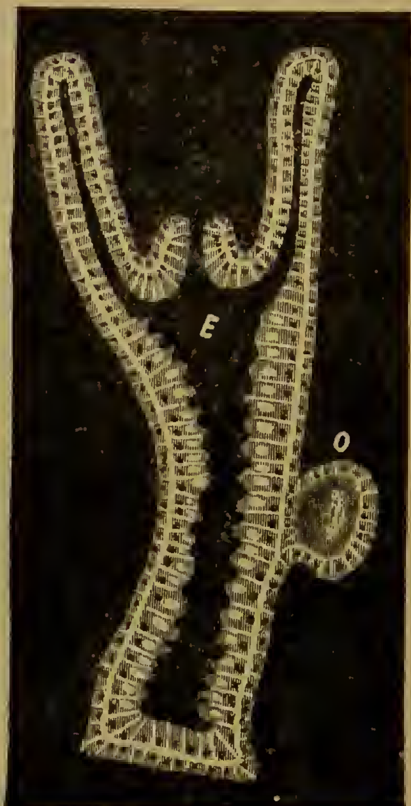

FIG. 36.—*Hydra:* diagrammatic longitudinal section passing through two tentacles, the mouth and an ovary, **O**. **E**. The enteron or primitive digestive cavity continuous with the tentacle cavities and opening to the exterior by the mouth. The body-wall consists of two layers separated by the mesoglœa, here shown as a white line.

are contained numerous thread-cells. The inner layer, or endoderm, is thicker, and its cells, where they line the enteron, have irregular surfaces, from which cilia and pseudopodia project into the enteric cavity. In these, in

Hydra viridis, are to be seen embedded numerous chlorophyll corpuscles, and thus the endoderm is very clearly marked off from the ectoderm. But in all Hydras it may be seen that between the two layers is a narrow band of a fibrous nature. This is composed, not of cells, but of a gelatinous secretion, into which fibres from the cells of both the ectoderm and the endoderm run. It is termed

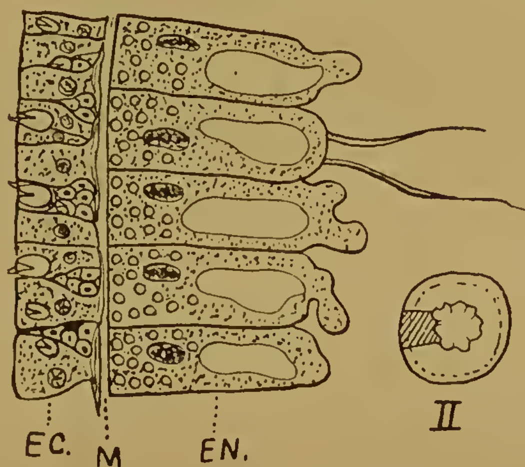

FIG. 37.—*Hydra:* part of a transverse section much magnified. **EC.** Ectoderm with protective cells, muscle-cells, nematocysts and interstitial-cells. **M.** Mesoglœa. **EN.** Endoderm : each cell has a large nucleus and a vacuole, and either pseudopodia or flagella projecting into the cavity of the enteron. They also contain numerous small chlorophyll bodies. The shaded area in the small circle at **II.** shows the part of the transverse section taken.

the **mesoglœa**, or supporting lamella, and is a skeletal structure of little importance in hydra.

In the more magnified transverse section the structures present are more plainly represented (Fig. 37). The ectoderm consists of several kinds of cells. There are (1) **covering cells**, the surface of which is exposed, and the more contracted bases of which reach the supporting lamina ; partly in these and partly between them are placed the fully formed thread-cells; in the angular spaces between the contracted bases of these covering cells are placed (2) the **interstitial cells**, which are small and irregular; they give rise to the cell masses which form the testes and the ovary, and among them are numerous young thread-cells; (3) large **ganglion** or nerve-cells, which do not reach the outer surface; each possesses a large nucleus and numerous branching protoplasmic processes, but cannot be seen except in macerated preparations; these are in conection with the thread-cells, in some cases with the muscle-cells, presently to be described, and with each other; (4) the **epithelial muscle-cells** are narrow cells, of which the surface is exposed on the outer side of the animal: the bases reach the supporting lamella, and are extended as long fibres closely applied to that lamella. These fibres thus come to form a thin layer immediately exterior to the supporting lamella; (5) at the pedal disc there are some large cells with clear contents which form a sticky secretion by which the animal clings to the surface to which it is applied.

The **endoderm cells** are very large, except in the region of the hypostome, where they form granular secreting cells. Those lining the greater part of the enteron possess large vacuoles: they may have two or three long cilia or flagella, or they may have active pseudopodia. Within them are to be seen food vacuoles, containing particles of food material taken from the enteron by the pseudopodia and the chlorophyll bodies.

Even in sections, the cells are so closely packed together that it is impossible to see all the details of their structure. For this purpose a living specimen should be placed in water containing a drop of acetic acid and a drop of osmic acid, and after a few minutes removed for several hours to a 0.2 per cent. solution of acetic acid in water. After this the specimen should be stained with picrocarmine solution. This course has the effect of hardening the cells and of rendering them easy to separate from each other. Small pieces of the Hydra should be placed on a slide in a drop of 50 per cent. glycerine and teased with needles. A few sharp taps with the point of a needle on the top of the cover-slip will assist the process of separation, and it will be found that many of the cells are completely isolated or adhere in little groups, so that with trouble the different kinds of cells may be picked out.

Let us now consider Hydra as a living organism. In the first place, it is composed of many cells of different kinds, and these are arranged in a definite way, so that the body consists of a hollow sac, the walls of which are composed of two distinct layers. The cells, however, are not, as in plants, surrounded and separated from each other by cell-walls. In the living condition it is only in a few cases that the cell outlines are visible : but when the protoplasm has been set and slightly shrunk by the action of reagents, the limits of the individual cells become apparent. The whole animal forms a mass of protoplasm so continuous that, without the aid of the blood-vessels and nerves of higher animals, every part is in organic connection with every other part, and the characters of the whole Hydra are a result of the combination of the cells. In the case of a colony of Protozoa, some of the cells may be injured or influenced without the influence being transferred to the whole colony, and certainly without the cells of the colony, by their combined action, responding to the stimulus. If a water flea come in contact with the tentacle of a Hydra, the muscle-cells of that tentacle begin to contract, so that the prey is drawn down towards the mouth. But other tentacles may also contract in such a definite way that they assist in the process of swallowing. Again, if the tentacles, or one of them, be touched with a foreign object, as, for instance, a needle, the whole Hydra suddenly contracts, and this is the result of the contractions of the muscle-cells all down the tentacles and body. When the animal creeps about, the motion is due to the concerted action of many separate muscle-cells contracting at the same time in different ways. In higher animals such co-ordination is effected, or at least assisted, by definite chains of nerve-cells and nerve-fibres connected with each other and with muscles and sense-organs. It is almost certain that in Hydra the nervous cells are not arranged with sufficient definiteness and regularity to be the chief agent. Most probably they are chiefly of local use and act in concert with the thread-cells. But the combination of all the cells to form an individual is seen clearly in other functions, where the nerve-cells certainly do not come into special operation.

All the cells of the body require nutritive material. But the functions of digestion are performed only by the endoderm cells for the whole organism. When food is taken into the enteron, digestive juices are poured on it from some of the endoderm cells, chiefly perhaps from the granular cells lining the hypostome. The other endoderm cells ingest the food particles in the enteron, and hand on nutritive materials to the ectoderm cells. Again, the function of sexual reproduction is undertaken for the whole Hydra by the few cells that form the ovary and the testis ; but, however independent these may appear, their formation is stimulated by starvation of the whole organism. The extent to which the individuality of the whole organism is stamped upon the separate cells is seen in budding. The bud is formed by a projection containing endoderm, mesoglœa, and ectoderm ; but it may grow out from any part of the column, and yet ultimately will reproduce the tentacles, the pedal disc, and the whole organism. Similarly, when a Hydra is cut across, from the cut end of the upper half, the lower part of a new Hydra grows out, while from the cut end of the lower half the cells required to complete the upper half grow out.

It is this co-operation of all the cells, this co-ordination by which the cells lose their own individuality in the new individuality of the whole animal, that is the great distinction between the Protozoa and the Metazoa. In higher forms of Metazoa, much of the interaction of the parts of the whole organism depends upon the existence of organs and systems common to the different parts—as, for instance, the nerves and the blood-vessels. But even in such higher animals there are many relations between the cells and organs which cannot be explained by the existence of sets of connecting organs ; and it is of importance to remember that, beginning with the simplest Metazoa, the cells and organs are living, co-operating parts of a living whole.

As we have seen, the food is of the kind that, in a previous chapter, we found to be characteristic of animals. When green algæ or chlorophyll bodies are present in the endoderm cells, these no doubt contribute to the food supply of their host, as they, like all chlorophyll bodies, cause the elaboration of starch from carbonic acid and water, and the oxygen liberated in the process may serve the purposes of the Hydra cells. If these bodies are separate plants living in Hydra, they are to be regarded, not as parasites, but as instances of the association of different cells for the advantage of each. This kind of association is named **symbiosis**. In **parasitism** the parasites live at the expense of their hosts ; in symbiosis both the host and the guest derive advantage from the association. In this case the plant cells are protected by their position within the Hydra, and the animal cells get both oxygen and starchy food from the plants.

Apart from such a special source of oxygen, the cells of Hydra obtain their supply of oxygen from air dissolved in the water. Most probably each cell takes in its own supply and in turn discharges carbonic acid. In the same way it is probable that each cell directly discharges its own waste products into the water, although contractile vacuoles have not been observed.

We have yet to consider the development of a new Hydra from the fertilised egg-cell (Fig. 38). While it still remains in the tissues of the mother, the egg-cell divides in two ; then each of these again divides, and after a number of divisions a little hollow sphere of cells termed the **blastula** is formed. The wall of the blastula at first consists of one layer of cells, but by the division of these cells an outer layer is produced. These have thick walls, and form a protective coat surrounding the egg when it drops from the ectoderm of the parent into the mud. The inner layer, which is the real embryo, is not perfectly regular. The cells at one end are larger and contain more yolk particles. When the further development takes place, the cells with the larger supply of food yolk multiply rapidly, and the cells so formed from them get pushed into the hollow of the blastula. When this has taken place the outer protective coat ruptures, and the young larva is liberated. By rapid division of all the cells it grows larger, and the cells in the middle, instead of occupying all the space, become arranged round a central

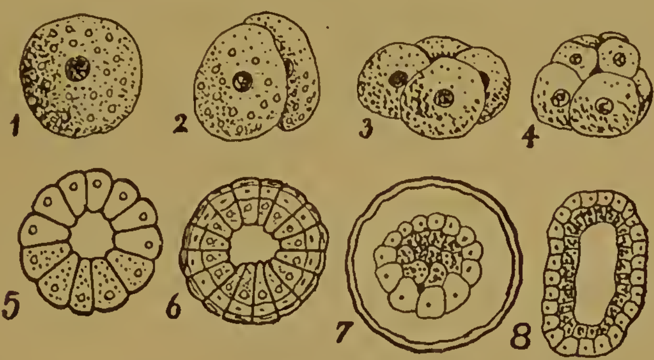

FIG. 38.—Diagram of development of *Hydra*. 1. Egg-cell fertilised and ready to divide. 2. Division into two. 3. Division into four. 4. Division into mulberry mass of which the lower cells are larger. 5. Section through blastosphere. 6. Formation of protective case. 7. Section through later stage; the embryo lies within the case which no longer shows its cellular structure; the larger cells at the lower end have multiplied rapidly and fill the interior. 8. The inner cells are arranged in a single layer so that the embryo is a two-walled hollow mass.

cavity—the enteron: the cells which migrated inwards from one pole form the endoderm, and the outer layer is the beginning of the ectoderm. The embryo grows longer. A gelatinous layer, the mesoglœa, is deposited between ectoderm and endoderm. A mouth aperture breaks through at one end, and round this the tentacles grow out as little buds. While these changes in shape take place, the cells, at first all much alike, become specialised into the adult condition.

Let us now sum up what we have learned with regard to the classification of the animal kingdom.

It is divided into two great groups, the **Protozoa** and the **Metazoa**.

The group **Protozoa** consists of all animals which throughout their lives are single cells, or which, if by cell division they form colonies, do not have the cells of the colony arranged and specialised to form definite tissues.

The group **Metazoa** consists of all multicellular animals which have the following characters:—

1. The cells are specialised and arranged to form definite tissues. Among these, except in the case of a few degenerate animals, there always are —(**A**) An outer layer or **ectoderm**.

(**B**) An inner layer or **endoderm** which surrounds an **enteron** or central digestive cavity.

2. The individuality of the separate cells is subordinated to, and influenced by, the individuality of the whole animal.

3. Sexual reproduction always occurs. There may be a series of generations produced asexually, as, for instance, by budding, but eventually sexual reproduction sets in. This takes place by the fusion of a male cell or spermatozoon with a female cell or ovum formed respectively in male organs or testes and female organs or ovaries.

CHAPTER XIII

THE GASTRULA, CŒLENTERATA, AND CŒLOMATA

AS the Protozoa are all small animals, and most of them invisible to the naked eye, it is plain that by far the majority of animals, the appearance of which is familiar to us, belong to the Metazoa. Among the Metazoa, for instance, are man himself and the quadrupeds, birds and reptiles, frogs and fishes, snails and cuttle-fish, insects and creatures like water-fleas and crabs and lobsters, worms and star-fish, and the host of soft, gelatinous animals like jelly-fish and sea-anemones, as well as their allies with hard skeletons such as corals. In all this variety of animal life there are many sets of animals which naturally fall into groups, and the science of zoology occupies itself largely with the investigation of the characters of these groups, and with the relations between them. Just as the whole animal kingdom falls naturally into two great groups, so also the Metazoa themselves belong to two distinct types, **Cœlenterata** and **Cœlomata**. To the simpler or lower of these Hydra, and a number of branched forms very similar to it, the medusæ or jelly-fish, and the sea-anemones and corals, belong. These differ in the shape and size of the body, and especially in the shape and arrangement of the enteron, in the number and arrangement of the tentacles, in the nature of the cells and the tissues, and in many other respects. But all of them are united by one great character; their bodies consist of a wall made up of ectoderm, mesoglœa, and endoderm, and this surrounds a single central cavity —the enteron. As the mesoglœa or middle lamella is not composed of cells, and so does not rank as a special layer, the cœlenterata are frequently termed **Diploblastica,** two-layered animals. The typical cœlenterate structure is in fact a little hollow sac or stomach with a mouth at one end, and with a wall composed of ectoderm and endoderm. No animal actually so simple as this is known, but a stage like this occurs in the development of many cœlenterata as well as of many of the higher group, the cœlomata, and it is probable that all the cœlomata sprang from a simple cœlenterate such as this. Let us try to form a picture of such a free living stomach or gastrula, as it is called, and of the changes in it which would lead up to the structure of higher animals. In Fig. 39, I., is represented a gastrula cut through the middle of the mouth and down through the middle of the body, so as to show the ectoderm and the endoderm. We know from study of existing Cœlenterates that at least three kinds of cells would appear in the ectoderm, simple protective cells (II. *a*), nerve cells (II. *b*), and muscle cells with long contractile muscle fibres (II. *c*). The protective cells remain as an external layer. We know that the nerve cells move inwards and form a network of ganglion cells underlying the external layer, while the muscle cells move still further in, so that they form a layer of fibres wrapping round the gastrula under the nervous layer, with a nucleus on each fibre to represent the original cell (Fig. 39, III.). The nervous layer remains between the outer cells and the muscle fibres, and so is able to register impressions or stimuli received from outside by the external cells, and to transmit the stimuli to the muscle fibres as messages to contract. In some Cœlenterates a similar set of nerve cells and muscle cells separate themselves from the endoderm and lie as in the first case with the muscle fibres nearest the mesoglœa. Between the two layers of muscle fibres formed in this way, there may be a small or large amount of mesoglœa deposited.

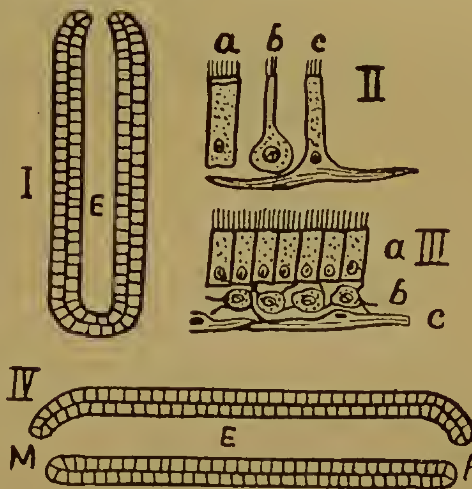

FIG. 39.—I. Diagram of Gastrula. E. Enteron. II. and III. Enlarged diagram of ectoderm cells. a. Protective; b. nervous; c. muscular: at II all three reach the outer surface; at III. the nerve cells have migrated inwards to form a layer under the protective cells, and the muscle cells form a similar layer still more internal. IV. Diagram of elongate gastrula with—M. mouth; E. enteron; A. anus.

The first change that we may suppose to occur in such a gastrula is a considerable elongation so that the mouth lies at one end of a long oval body. Then at the opposite end from the mouth an aperture into the enteron appears. The animal is now an elongated cylinder with a mouth at one end, and an anus at the other (Fig. 39, IV.). The food is taken in by the mouth, passed into the alimentary canal, or enteron, where it is digested and absorbed by the endoderm cells, while the indigestible débris is extruded by the anus. Such an animal has now an anterior and a posterior end, and if it moved through the water, one would expect it to go with the mouth end first, so that food particles coming in its way might be swallowed.

The next stage of importance occurs by the enormous thickening of the mesoglœa so that the endoderm and ectoderm lie at a considerable distance from each other. Fig. 40, I., represents a longitudinal, and 40, II, a transverse section through such an animal. Both ectoderm and endoderm are broken up into three layers, of which the inner or muscular layer lies next the thick mesoglœa. In some living Cœlenterates the mesoglœa is very thick, and into it the muscle processes dip, and even cells from the ectoderm and endoderm migrate. Such a condition gives the starting-point for the **Cœlomata**. Externally (Fig. 40, I. and II.) is the protective layer of cells, then comes the nervous layer, then the muscular layer, then a wide space filled with a gelatinous excretion and containing cells which have wandered in from the ectoderm and endoderm, then comes the endodermal muscle layer, then the nervous layer, and then the layer of digestive cells, and lastly, in the centre of the animal, the cavity of the gut or enteron. In actually existing **Cœlomata**, however, there is no mesoglœa, but a space occupied by a number of structures. Into this space wandering cells migrate and form the blood and blood-vessels and the connective tissue and skeleton. The muscular layers, instead of being formed from the ectoderm and endoderm in definite layers, usually arise as solid buds of cells coming chiefly from the endoderm. These afterwards arrange them-

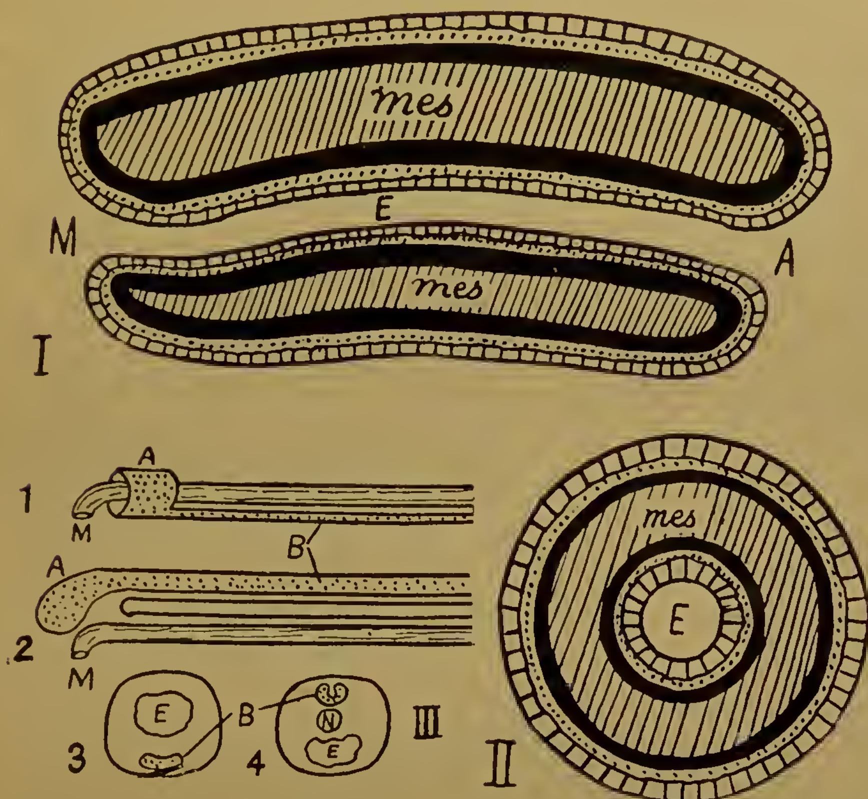

FIG. 40.—I. Longitudinal, **II.** Transverse section through an animal with very thick mesoglœa, mouth, anus, enteron; ectoderm and endoderm broken up into three layers, muscular next the mesoglœa, then nervous, and then protective in the ectoderm, digestive in endoderm. In Cœlomates mesenchyme tissues and the cœlome occupy the space here filled by mesoglœa.

M. Mouth; **A.** anus; **E.** enteron; **Mes.** mesoglœa. Black layer is muscle, dotted layer is nervous; layer divided into cells is protective in ectoderm, digestive in endoderm.

III. Nervous system of Cœlomates—**1.** An invertebrate type; the nervous system forms a ring round the alimentary canal in front and a longitudinal band below it. **2.** The vertebrate type; the nervous system forms a bulb in front, a tube behind, both above the alimentary canal and separated from it by a special rod of cells—the notochord. **3.** Crcss section through posterior part of **1.** **4.** Cross section through posterior part of **2.**

M. Mouth; **A.** anterior; **B.** posterior parts of nervous system; **E** enteron; **N.** notochord.

selves round the gut and round the inner side of the body-wall so that their final position is similar to that in the diagrams of Fig. 40. These muscle layers and the immigrating vascular and skeletal tissues fill up a considerable part of the space originally occupied by the mesoglœa. But in cœlomates there is also present a special cavity lying within the muscular layers and lined by a special epithelium. This space is called the **cœlome,** and its epithelium is the **cœlomic epithelium.** The existence of this cavity lying between the alimentary canal or enteron and the body-wall is the leading characteristic of **Cœlomates**, from which their name is derived. The buds of cells which form the muscles, and the cells which form the cœlomic epithelium, are termed the **mesoblast** or middle layer. With the mesoblast the wandering cells which form the blood and skeleton are often grouped, but it is better to keep them separate in idea under the name **mesenchyme.** The Cœlomates, on account of these sets of cells lying between the endoderm and the ectoderm, are often distinguished as the **Triploblastica,** three-layered animals, but it is necessary to remember that this middle layer is not a simple layer like the outer and inner layers, but is a composite structure composed of contributions from the others.

Finally we have to consider a set of changes which occurs in the nervous layer. It will be remembered that there are two layers of this. The endodermal nervous layer surrounding the alimentary canal either disappears or becomes the special nervous apparatus of the wall of the gut. The ectodermal nervous layer gives rise to the chief nervous structures of the adult, and, among Cœlenterates generally, it becomes specially thickened in certain regions. Thus even in Hydra the nerve cells are more abundant on the tentacles. In many anemones this occurs very markedly, while in medusæ special thickenings or concentrations occur round the tentacles, round the margin of the umbrella-like swimming bell, and in other places. Instead of forming a scattered layer of ganglion cells these become aggregated and concentrated in tracts and regions where the nervous cells are specially useful. When the gastrula became elongated and took to moving mouth first through the water it is plain that it was the anterior region of the body that came first in connection with the outer world. Accordingly it is in the anterior region round and above and below the mouth that special developments of the nervous layer arise among cœlomates. Most often in the region above and in front of the mouth a specially large collection of nerve cells occurs, and such a collection may be called a **brain,** while the part of the body in which it lies may be distinguished as a head. In addition to this thickening of the ectodermal nervous layer in the front end of the body, thickenings in other regions occur among different cœlomate animals. Of these, two types require attention. In many animals like earthworms and leeches, crayfish and lobsters, and in insects, in addition to the nervous layer in the anterior region there is a concentration, or special development of it, all along the under surface in the middle line from the mouth to the anus (Fig. 40, III. 1 and 3). As this is the arrangement in the most commonly known animals that do not possess a backbone, it is often spoken of as the invertebrate type of nervous system. On the other hand, among those animals that do possess a backbone, such as fishes, frogs, reptiles, birds, and mammals, there is a special concentration of the nervous system along the middle line of the upper or posterior surface (Fig. 40, III. 2 and 4). This is the spinal cord, which runs from the brain down the middle line of the back, protected by the arches of the backbone.

Let us now sum up the characters of the two groups into which the Metazoa are divided. The Cœlenterata consist of Metazoa built upon the type of the gastrula. In them the body-wall consists of two cellular layers, the ectoderm and the endoderm, separated by the mesoglœa, a supporting layer which is not composed of cells. The two-layered wall surrounds a central digestive cavity, the enteron, which communicates with the exterior by an aperture serving both as mouth and anus. The Cœlomata contain those Metazoa in which, in addition to the ectoderm or endoderm, there is a third set of cells, the mesoblast, lying between them. The cells of this are derived from the ectoderm and the endoderm, by the partial or complete mingling of several sources, of which the most important are three, muscle buds representing the endodermal and ectodermal muscular layers, cœlomic epithelium, and mesenchyme or vascular and skeletal cells. Within the mesoblast there is a second cavity, surrounding the enteron or primitive digestive cavity, and called the cœlome. The ectodermal nervous layer becomes concentrated in at least two important regions, an anterior region round the mouth, and a longitudinal tract along the body.

CHAPTER XIV

THE EARTHWORM

THE earthworm is a convenient type of cœlomate to examine, as it is large enough to dissect and soft enough to cut into microscopic sections without great difficulty. Earthworms belong to many different genera, and are found all over the world, living in the earth, in mud, or some of them in water. Most typical examples live in the ground. As Darwin showed, their food consists of organic matter, chiefly vegetable, which they obtain from the soil by passing great quantities of earth through their alimentary canals. In this process the nutritious organic matter is absorbed by the alimentary canal, and the indigestible part is discharged by the anus in a finely triturated condition, forming the worm-castings familiar to every one. In this way worms pass a very large quantity of the soil through their bodies, and, as the castings are deposited on the surface of the ground, stones and other objects on the surface are gradually undermined, and in the course of years buried in the soil.

The different kinds of earthworms vary in size. The smallest are no thicker than a piece of packthread, and may be less than a quarter of an inch in length. Some of the largest, as, for instance, the giant earthworm of

Australia, may be six to eight feet long, and at the thickest region of the body have a girth the size of a man's wrist. The common earthworms of England belong to more than one genus, and there are several species. The two genera most common in England are *Lumbricus* and *Allolobophora*. In the English species the genera may be distinguished by the dorsal surface of the first segment. In *Lumbricus* the prostomium is prolonged back to the constriction between the first and second segments ; in *Allolobophora* the prostomium does not reach so far (Fig. 41, *a*, *b*). The common large worm, about six inches long, with flattened tail and whiter lower surface, is *Allolobophora terrestris*, commonly in error called *Lumbricus terrestris*. The smaller sized common red worm with white clitellum is a *Lumbricus*. Into the separate characters of species it is unnecessary to enter, as any of them will serve our present purpose. For the most part they live underground, and specimens found crawling on the surface are generally diseased. But on a summer evening, especially after rain, earthworms may be seen in immense numbers on the surface of any lawn. Each remains in connection with its burrow by the flattened part of the tail, and the slightest touch or vibration on the ground causes it instantly to retire within the burrow. The mouth of the burrow is guarded, sometimes by a small stone, more often by a leaf pulled down stalk first. The sides of the burrow are always damp and slimy, the slime being a secretion from the glandular cells on the outer surface of the skin, and possibly also a fluid discharged from the cœlome of the animal through a series of dorsal pores.

The earthworm is an elongated animal, pointed at both ends, and flattened towards the posterior end. The colour varies from a red-brown to a pale yellow-brown, and is darker on the upper surface and generally at the anterior end. It is constricted externally into a number of rings or **somites**, of which there may be different numbers in mature specimens of the same species. These may be so few as sixty-eight, or may be more than two hundred. This is the first instance we have had of what is known as **segmentation**, and the segmentation is called **metameric** when the segments form a longitudinal row.

It is a phenomenon of frequent occurrence among cœlomates. Sometimes, as in many worms, in lobsters and crayfish, and in insects, the segmentation is obvious on the outer side of the body. But in addition, many of the internal organs, such as muscles, nervous structures, genital organs, and bony parts (as the backbone of a fish or of a man) also may be segmented. The segmentation of the internal organs may correspond to that of the external surface of the animal, so that the whole body is broken up into a series of rings, each ring being practically a repetition of the ring next in front. More often, as in man, the segmentations of the different internal organs do not completely agree and do not correspond with external marks. Thus our body can hardly be said to be segmented externally. At the most it is broken up into three regions—the head, the fore part of the trunk with the arms, and the hind part of the trunk with the legs. To a certain extent the muscles are segmented, but these segments do not correspond with the divisions of the outer surface. The lungs, the heart, the alimentary canal, and the kidneys are unsegmented, while the nerves, the ribs, and the backbone are highly segmented. So far as observation goes segmentation is a phenomenon that may occur in almost any cœlomate tissue, and although the result of it is to produce an appearance of similarity—just as from a balloon at a considerable height a row of elephants and a row of corn-ricks would closely resemble each other—there is no necessity to suppose that segmented animals or tissues are really more like each other than are unsegmented animals or tissues.

The whole of the body is invested with a delicate transparent iridescent cuticle. This is not composed of cells, but is formed as a secretion by the external cells of the body-wall. When a worm is placed in spirit the cuticle becomes separated from the underlying cells, and strips off easily. If the anterior, more pointed end be examined carefully with the naked eye, and with a small pocket lens, it may be seen that the most anterior segment is complete posteriorly, but that it ends anteriorly in a rounded lobe overhanging a wide aperture looking downwards and forwards. The aperture is the mouth; the projecting lobe is termed the **prostomium**, and if a living worm be examined one can see that the prostomium is used as a delicate organ of touch, and that it is more sensitive than the rest of the body. The posterior segment of the body has a vertical slit between two humid lips, on the posterior or terminal surface. This is the **anus**. Near the anterior end of the body—actually in segments 29–35—there is a whitish, swollen, saddle-shaped patch—the **clitellum**. This is most apparent on the back of the animal, and, except during the breeding season, it is not a conspicuous object. It is a patch of the ectoderm, the walls of which are glandular and secrete a **cocoon**, within which the mature ova and spermatozoa are placed.

If a finger be passed along the ventral flatter surface of an Earthworm from the posterior to the anterior region, it will be felt that that surface is not smooth like the rest of the earthworm, but is studded with sharp bristle-like points. These are curved **S**-shaped bristles of a horny material which is common among invertebrate animals, forming, for instance, the hard outer cuticle of beetles, and called **chitin.** In the common earthworm there are eight setæ on each segment except the anterior and posterior segments (Fig. 41). These eight are arranged in four longitudinal rows (two lateral and two ventral), the spaces between the longitudinal rows being flattened. The ventral rows are on the paler ventral surface: the lateral rows lie parallel with them, where the darker colouring of the upper part of the body begins. The setæ are embedded in blind sacs of the epidermis, projecting into the cœlome, and they are formed by an excretion from the cells lining the sacs. A powerful set of muscles is attached to each sac (Fig. 45.

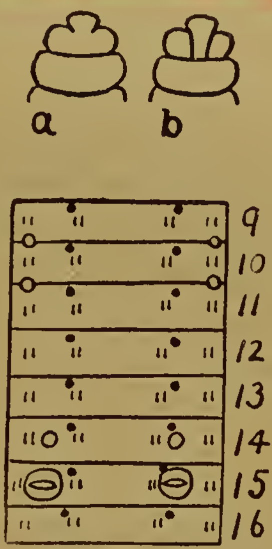

FIG. 41.—**a.** Prostomium and first and second segments of Allolobophora; **b.** same of Lumbricus. The lower figure is a diagram of the ventral aspect of segments (**9–16**) of an earthworm. The short strokes, arranged in pairs, are the setæ: the round dots in front of the outer setæ of the inner pairs are the nephridial pores. The spermathecal apertures are between **9** and **10**, and **10** and **11**; the apertures of the egg-ducts are in **14**, and of the male-ducts in **15**.

s m), and by means of these muscles the setæ form the locomotor apparatus of the earthworm. When cast off, the setæ are replaced, and young setæ occasionally may be seen alongside mature examples.

In addition to the mouth and anus there are other external apertures. The **dorsal** or **peritoneal pores** are small apertures situated in the middle of the constrictions separating the segments. If the body of a newly killed earthworm be gently squeezed, a small drop of fluid exudes from each pore, and it may be seen that there is one of them in every constriction except near the front end of the body.

The orifices of the excretory organs, or **nephridia**, are very small, but in large specimens they may be seen with the aid of a hand lens. There are two orifices in each segment; each lies just outside and in front of the external seta of the inner longitudinal row.

The sexual apertures are more conspicuous (Fig. 41). In the common earthworm, on the ventral surface of the 15th segment (the segments should be counted, as variations in the position may occur) are a pair of large slit-like apertures guarded by swollen, light-coloured, tumid lips. These are the external openings of the male organs. In a line with these, on the segment next in front, are a pair of smaller apertures, the female openings.

The ventral surface of a few of the segments in front of this (9 to 11), especially in the breeding season, is swollen, and resembles the clitellum. In line with the lateral setæ at each side there is present a small opening between the 9th and 10th, and between the 10th and 11th somites. These are openings of accessory reproductive organs termed the **spermathecæ**.

All the external characters should be made out on a living or a newly killed worm.

Killing by chloroform contracts the muscles and distorts the animal. The dissection should be performed upon as large a specimen as possible, killed by immersion in methylated spirit for two minutes, and then washed under the tap for half an hour. A specimen so treated is quite limp, and should be dissected under water in a shallow dish provided with a false bottom into which pins will stick. A sheet of cork weighted with lead, or a layer of paraffin run into the bottom, serve this purpose equally well. In the course of dissection the dish should be placed under the tap at frequent intervals, so that all *débris* that makes the water cloudy may be removed. The dorsal wall must now be slit up carefully along the middle line, and the two flaps pinned back to the cork. The spacious cœlome or body cavity, containing the alimentary canal and the internal organs, is exposed by this incision, and one sees at once that it is divided by a series of **mesenteric septa** — delicate membranous partitions usually coinciding with the constrictions between the segments, except in front of the fourth segment. Occasionally septa may be more numerous than the segments. In order to pin out the flaps widely and expose the internal organs fully, it will be found necessary to cut through the septal attachments to the body-wall for a short distance on each side of the original longitudinal incision.

Before proceeding further with the dissection, the general arrangement of the organs should be examined carefully.

Anteriorly is the **pharynx,** a wide, muscular sac reaching from the anterior end to nearly the 8th segment ; behind the gut narrows and is overlaid by other structures, but about the 20th segment it is again visible as a rounded muscular mass—the **gizzard**, which is separated by a constriction from the intestine. The latter is sacculated, expanding in the segments and constricted at the septa ; near the posterior end of the body it gets rounder, and narrows until it reaches the anus. The outer or cœlomic

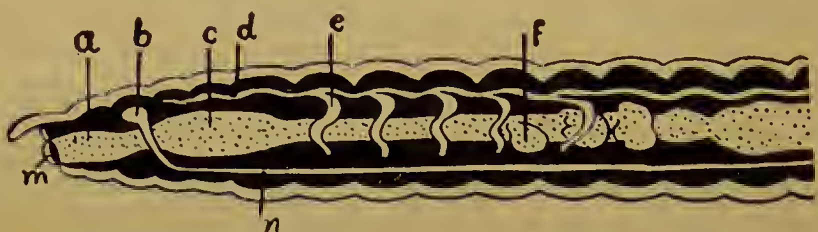

FIG. 42.—Diagrammatic longitudinal view of the fore-part of an Earthworm opened from the left side. The cœlome is the black space ; the alimentary canal is the dotted tube passing from the mouth backwards. The nervous system and blood vessels are in white. **m.** mouth ; **a.** wall of buccal cavity ; **b.** cerebral ganglion from which the nerve collar runs round the alimentary canal to be continued as **n**, the ventral nerve-cord ; **c.** pharynx ; **d.** dorsal blood-vessel ; **e.** anterior of the five hearts which lead from **d.** round the œsophagus ; **f.** calciferous pouch ; in the succeeding two segments are the calciferous glands.

surface of the intestine is covered by a greenish-yellow layer—the **chloragogen cells.** Running along the dorsal middle line of the alimentary canal from the hinder end of the body is a bright red tube—the **dorsal blood-vessel.** It ends anteriorly in the region of the pharynx, over which it ramifies. In each segment a pair of blood-vessels can be seen given off from it, and running round the inner side of the body-wall. In segments 7 to 11 there are five large and conspicuous vessels—the **hearts.** In the living worm their muscular walls are contractile, and they serve to propel the blood.

The alimentary canal and the other organs are generally covered and obscured by large, whitish, hollow, irregular masses stretching from about the 8th to the 15th segments. These are the **vesiculæ seminales**—reservoirs of the seminal fluid. In the breeding season (Fig. 43, right side) they are so large and conspicuous that, even before the earthworm is opened, they may be seen bulging the body-wall out. There are three at each side and a large median one. When they are not well developed, there may be seen between them three pairs of expansions of the wall of the alimentary canal between the pharynx and the gizzard. The anterior pair, about the 10th segment, are the **calciferous pouches**—glistening, whitish organs; and the succeeding two pairs in the 11th and 12th segments are the **œsophageal** or **calciferous glands.** Immediately behind them, the alimentary canal expands to form a soft-walled sac called the **crop**, which passes into the muscular **gizzard.** In the 9th and 10th segments, laterally just under the edge of the vesiculæ seminales, may be seen two pairs of rounded pinkish bodies—the **spermathecæ**—the external openings of which have already been described.

The septa are specially strong in the anterior part of the body, and owing to the lateral stretching of the body when the flaps were pinned out, it will be found that the septa are bent so that they overlap each other. But in the region behind the gizzard, the segments are larger and the septa straighter. In this region a pair of **nephridia** may be seen in each segment. Each nephridium is a small coiled structure closely attached to a mesentery, and lying under and to the side of the alimentary canal.

For more detailed dissection the different organs must be taken separately, and if it be found that the examination of one set of organs has injured another set, another worm should be dissected, special care being taken with the organs imperfectly seen in the first.

Alimentary canal (Fig. 42). This consists of a straight tube running from the mouth, which opens from the ventral side of the 1st segment, and is overhung by the prostomial lobe, to the anus, which is posterior and surrounded by the last segment. The mouth cavity or **buccal cavity** leads into a very short constricted part, which is surrounded by the nerve collar, and this leads into a wide, muscular **pharynx**, which extends to the 6th segment, and is bound to the body-wall by fan-shaped strands of muscle. From the posterior end of this emerges a narrow **œsophagus**, which runs back to the 14th segment. Midway on this are three pairs of protuberances—the calciferous pouches and glands. The first pair lie in segment 10, and have a narrow opening into the gut. The second and third pairs lie in segments 11 and 12, and are closed cavities, the walls of which are lined by horizontal lamellæ. The glands when opened are found to contain a milky-white fluid secretion. Under the microscope this is seen to contain numerous rounded solid bodies, and, in the first pair, rhombohedra and large concretions. These are calcareous bodies, soluble in acetic acid with the evolution of carbonic acid. The function of the secretion is unknown. In the 14th segment the œsophagus begins to expand, and widens until the 17th segment, where it forms a large muscular **gizzard.** The expansion in front of the gizzard is sometimes called the **crop,** but it has no special function. The gizzard is a grinding or triturating organ, and its interior is lined by a thick, chitinous secretion which protects the wall while the stones and hard particles taken in are rubbed down. The gizzard is to be considered as a modified part of the œsophagus. Behind it, the alimentary canal passes into the sacculated **intestine,** which passes straight back to the anus. The pharynx should now be cut across, and the whole alimentary canal from the cut portion to the anus should be removed from the body, slit open along one side, washed out, and examined. In the intestine a striking feature is the **typhlosole**—a fold of the dorsal wall hanging down half-way into the cavity of the gut (Fig. 45). This ceases a short distance in front of the anus.

Cœlome. The spacious cavity in which the alimentary canal was lying, and which is broken up into successive segments by the septa, is the cœlome. It is lined throughout by a delicate flattened layer of cells, the nuclei of which can be seen in transverse sections. This layer, or epithelium, is reflected over all the organs lying in the cœlome. The cœlome communicates with the exterior by the dorsal pores and also through the nephridia and the genital ducts. The fluid within it contains amœboid corpuscles and large round cells loaded with granules.

To examine the cœlomic fluid and the blood, a small earthworm should be killed with chloroform. As soon as it is dead the cœlome should be opened by a small slit in the middle dorsal line, care being taken to avoid the dorsal blood-vessel. The slit should be large enough to introduce a very small pipette or the point of a camel's-hair brush, by which drops of the cœlomic fluid are to be transferred to a glass slide. These drops may be examined in the fresh condition under a cover-glass, but it is advantageous to kill and fix the cœlomic corpuscles by holding the glass slide with the drop on its under surface over a few drops of osmic acid in a watch-glass. The drop on the slide must not be allowed to touch the acid. The vapour rising from the watch-glass is sufficient for the purpose.

The blood is to be examined in the same way, a few drops being removed from a large blood-vessel. The blood consists of a pale-yellow serum in which float colourless corpuscles. The colour, which is red in a thicker layer or when seen in the blood-vessel, is due to **hæmoglobin**, the same pigment as that found in the blood of vertebrates. But in these the serum is colourless, and the hæmoglobin is contained in the corpuscles.

The corpuscles of the earthworm are very small. Each contains a large nucleus similar to those which are found in the cells lining the blood-vessels. These corpuscles are therefore unlike either the red or the amœboid corpuscles of vertebrates. The amœboid corpuscles found in the cœlome are most probably the representatives of the white corpuscles of vertebrates, and, like them, they have been observed in the process of devouring, and so destroying foreign bodies like bacteria which have found their way into the body of the earthworm.

The lining epithelium is modified in certain special regions. The yellowish layer of **chloragogen** cells covering the intestine has already been mentioned. These are in special connection with the plexus of blood-vessels which ramifies over the intestine (Fig. 45); they extract waste substances from the blood, and discharge them into the cœlome, from which they are removed by the **nephridia.**

Next, it is on the lining epithelium of the cœlome that the sexual cells are produced ; the testes and the ovaries, presently to be described, are little buds of cells jutting into the body cavity from its lining wall, and the sexual products escape from the cœlome by the sexual ducts.

Sexual organs (Fig. 43). The **ovaries** are a pair of minute, rounded, conical bodies projecting into the cavity of segment 13 from the posterior wall of the septum separating segment 13 from segment 12. They are very small except in the breeding season. In order to see them one must carefully raise the upper edge of the septum to which they are attached, by a small pair of forceps, when the little conical projections are visible, one at each side of the middle line. Hold up the septum with the left hand ; in this position an ovary may be scraped off with the edge of a sharp scalpel and then removed from the water to a slide with a camel's-hair brush and examined in water or glycerine. Staining on the slide with a quickly acting pigment like eosin is an advantage. At the pointed or free end, if the worm were sexually mature, lie ripe eggs. These are large round cells with a distinct wall, the **vitelline membrane,** granular cell-body, which consists of protoplasm loaded with spherical particles of **food-yolk,** and with a large round nucleus. Behind them lie younger ova in different stages of ripeness, and these pass into a mass of small cells, which were in continuity with the cœlomic epithelium. In the 12th segment occasionally there are to be found, especially in young worms, a second pair of

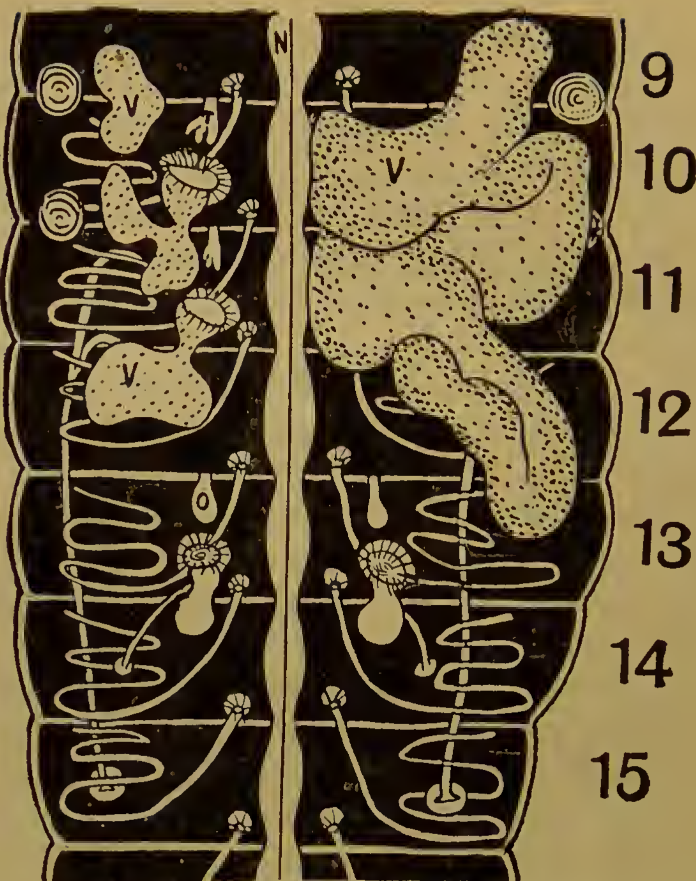

FIG. 43.—Genital Segments, diagrammatic dorsal view, the intestine having been removed. The cœlome is black, the septa and nervous cord (**N**) white. The right half represents a mature, the left an immature, worm.

Spermathecæ: laterally in segment **9** bulging out septum between **9** and **10**; the second pair lie similarly in segment **10**, but the right is covered by the Vesiculæ seminales. **Vesiculæ seminales (V)**, on the right, form large bulbous masses from segments **9** to **13**; on the left, they lie on septa **9–10**, **10–11**, and **11–12**, the two latter communicating with the seminal funnels. **Testes (T)**, on the left, attached to the posterior wall of septa, **9–10** and **10–11**; on the right, concealed by Vesiculæ seminales. **Vas deferens** runs back from the seminal funnels under the nephridial coils to segment **15**. **Ovaries (O)**, attached to septum **12–13** in line with the testes. Opposite them are the oviducal funnels in segment **13**, with the **receptacula ovorum** bulging into **14**; from the side of the funnels the oviducts run back to openings in **14**.

Nephridia. The preseptal funnels lie on the sides of the nerve cord in every segment; the coils are visible except when they are covered by other organs. (Partly after Beddard.)

very small ovaries similarly attached to the septum between 12 and 11.

The septum between 13 and 14 must next be raised with the forceps, and there is to be seen closely applied to its anterior face, and exactly opposite the ovaries, a pair of short, wide funnels. These are the openings of the oviducts, and these ducts are short tubes running through the septum to the external openings on segment 14. Each, as it passes through the septum, is in close connection with a small backward-directed pouch of the septum projecting into segment 14. The walls of these are highly vascular, and so are conspicuous, although small. They are egg-sacs, in which eggs may sometimes be found, but in the common earthworm they are of little importance. In some of its allies, however, these egg-sacs are enormous, extending a great way down the body. The **testes**, the male organs corresponding to the ovaries of the female, consist of two pairs lying attached to the posterior face of the septa between 9 and 10 and between 10 and 11, in positions in line with the ovaries. Attached to the anterior faces of the septa, one opposite each testis, are the **seminal funnels**. These are large opaque-white membranous funnels, the walls of which are much folded and are lined on the inside by ciliated cells. Each funnel passes into a small tube—the **vas efferens**—which pierces the septal wall. The two vasa efferentia of each side unite in segment 12 to form at each side a single narrow tube, the **vas deferens**, which runs back to the male opening on each side of the middle line on the ventral surface of segment 15.

In immature specimens of either *Allolobophora* or of *Lumbricus*—that is to say, of any of the common earthworms—the testes, funnels, and ducts are visible when the alimentary canal has been removed (Fig. 43, left side). But the case is different in adults. In *Lumbricus*, in both the 10th and 11th segments, there is a large median sac formed as an outgrowth of the septal wall called the **median sperm reservoir** or **vesicula seminalis**. These reservoirs communicate with paired sperm sacs in segments 9, 11, and 12, and the whole set of sacs forms a prominent irregular white set of pouches, which contain a thick fluid in which are floating developing masses of spermatozoa. The median reservoirs enclose the testes and the funnels, and it is necessary to slit them open and wash out the contents before the testes and funnels can be seen. In *Allolobophora*, and therefore in the common worm used for dissection, there are no median reservoirs, but there are three pairs of seminal sacs corresponding to the paired outgrowths present in *Lumbricus*. In the mature condition these are large and bloated and have contents similar to those of *Lumbricus*. Occasionally they grow into each other, but to find the testes it is necessary not to cut into them, but to displace them or to remove them entirely.

A small portion of a testis should be removed, stained with eosin, and teased with needles. It contains small irregular cells with large nuclei. these are parts of the **germinal epithelium**, which, as in the case of the ovary, is a special patch of the cœlomic epithelium. Among them are present larger cells produced from them. These larger cells are the **spermatophores**, each of which by division gives rise to a large number of **spermatozoa**. The spermatophores are set free from the testis as oval tuberculated masses containing many nuclei, and they find their way into the sperm reservoirs. A small drop of the milky juice contained in the sperm sacs or sperm reservoirs must be stirred into a large drop of normal salt solution on a slide and covered with a cover-slip. It will be seen to contain numerous spermatophores in different stages. These are (1) Mulberry-shaped multi-nucleated masses as in the testis. (2) Masses in which the protoplasm is arranging itself round each nucleus and projecting outwards as a filament. (3) Stages in which the filaments are prolonged to form the tails of the spermatozoa. (4) Final stages in which each spermatophore consists of a central unchanged portion surrounded by tufts of spermatozoa. Occasionally free spermatozoa, each with an elongated head and a long hair-like tail, may be seen.

Among the contents of the sperm-reservoirs almost invariably there are present stages of an unicellular animal belonging to the genus *Monocystis*. This is one of a group of parasitic Protozoa named Gregarines, which live as parasites in the bodies of cœlomates. The fully grown cell is a large granular mass of protoplasm enclosed in an elongated oval cell-wall with pointed ends. Normal salt solution does not kill it, and its shape constantly changes as it wriggles about in the fluid. There may be also seen large round cysts produced by the conjugation of two cells. The cysts are packed full of small oval spores each of which has a hard wall enclosing a tiny elongate mass of protoplasm. Ruptured cysts and free spores are of frequent occurrence. These Gregarines, unlike the algæ found in endoderm of Hydra, are *parasites*; so far as is known their presence is attended with no benefit to their host, and in many cases they produce diseases. The bodies of earthworms which may be found away from their burrows lying in a half-dead condition on the surface of the ground, contain numerous Gregarines of different kinds.

Spermathecæ. Lying in the ninth and tenth segments are a pair of very peculiar accessory reproductive organs —the spermathecæ. These two pairs of rounded globular sacs open directly to the exterior by the spermathecal pores. They contain seminal fluid received from another worm during copulation.

Nervous system. When the alimentary canal, behind the pharynx, and the sperm reservoirs have been removed, there is visible, stretching along the floor of the body cavity from one end to the other, a delicate white cord. This is the ventral nervous chain. It is expanded in the middle of each segment, the swellings, or **ganglia**, being larger in the hinder parts of the body, and in each segment three pairs of short nerves run from them into the body wall. If this ventral chain be traced forwards under the pharynx it may be seen in the fourth segment to separate into two branches, each of which bends upwards and forwards, the two forming a collar round the œsophagus in front of the pharynx. The dorsal part of the collar is formed by two pear-shaped ganglia lying on the constriction in front of the pharynx and united by their broad ends. These two are the **supra-œsophageal ganglia** or brain, and from them nerves run forward to end in the epidermis of the prostomium.

Circulatory system. Some of the details of this can be seen in the dissection of the various tissues and organs described, but it is useful to examine this system in a fresh worm. This should be dissected under spirit.

The blood-vessels are recognised by their bright red colour.

The **dorsal** vessel (Fig. 45 (1)) may be seen through the skin in a living animal. It runs from the posterior end to the pharynx, closely applied to the alimentary canal. The flow of blood is from behind forwards, and the vessel is rhythmically contractile. The **ventral** vessel (Fig. 45 (2)) is a median vessel running backwards below the alimentary canal, along the whole length of the animal. Anteriorly it communicates with the dorsal vessel by a series of capillaries. The **subneural** vessel runs along the whole length of the animal under the nerve cord within the sheath. The **lateral neural** vessels run along the whole length of the nerve cord also embedded in the sheath. These are the main trunks of the vascular system, and they are connected with each other by a complicated system of capillaries.

The hearts are five pairs of large contractile vessels (Fig. 42) running round the œsophagus in segments 7 to 11 from the dorsal to the ventral vessel. During life the contractions pass from above downwards. In each segment a pair of vessels run round the body-wall from the dorsal to the subneural vessels. In each segment at least two vessels are given off on each side from the dorsal vessel, and immediately break up into a set of meshes ramifying all over the surface of the intestine. These are covered and obscured by the chloragogen cells. A longitudinal band of this meshwork at each side is specially conspicuous, and these two are sometimes called the **lateral longitudinal vessels.** The nephridia receive a blood-supply from the ventral vessel: a small blood-vessel runs from this to each nephridium, upon which it breaks up into capillaries. From these a vessel runs back to the subneural vessel.

Nephridia (Fig. 44). To examine these excretory organs in detail it is important that the septa should not have been torn or stretched. When the alimentary

FIG. 44.—Enlarged diagrammatic view of a Nephridium. **4**. The pre-septal part and the funnel; this passes through the septum **S** into **2**, the middle loop. **1** is the inner loop; **3** the outer loop. (Partly after Benham.)

canal has been removed, the worm must be washed under the tap. Each nephridium is then seen with the aid of a hand-lens as a delicate tube or loop, whitish in colour (Fig. 43), and extending in the segmental cavity from the mid-ventral line almost to the mid-dorsal line, and is suspended to the septum by a mesentery of its own. It is divisible into a preseptal region lying in front of the segment which bears the external aperture and a much larger post-septal region. The pre-septal region is very short, and consists of a funnel opening into the cœlomic cavity and a short tube passing through the septum to form the post-septal part (Fig. 44 (4)). This part should be cut out and examined in a drop of normal salt solution under a high power. The funnel consists of a number of tall columnar cells lined by strong cilia, the motions of which sweep a current from the cœlome into the tube. The funnel opens into a narrow tube which is hollowed out of the interior of the rod of cells through which it passes. The post-septal portion consists of three loops, and the intracellular tube passes suddenly into the ascending limb of the middle of these, and then runs down the descending limb and up and then down the inner loop, and back again to the middle loop, which it first ascends and then descends. This part of the nephridium is the largest ; it is ciliated in places, and the ascending and descending parts are twisted about each other. (In the diagram they are drawn straight, on account of simplification.) The narrow part, after leaving the middle loop, crosses to the inner loop and runs up and down that : this part of the tube is glandular and the cavity is much wider. Next it runs up and down the middle loop again, and finally forms the very wide tube of the outer loop which ends in the external aperture.

A dense network of blood capillaries surrounds and ramifies through the walls of the middle and inner tubes.

Minuter details of the anatomy of the earthworm must be studied by means of sections. As the amount of earthy matter in the intestine blunts the razor and tears the sections, it is advisable to keep the worms for a few days in damp moss ; or if they are placed in salt and water for a few minutes before killing they will frequently discharge the contents of the intestine. A small specimen should be chosen, and killed by immersion in methylated spirits for about two minutes. Then it should be removed to a cold saturated solution of corrosive sublimate in water to which one per cent of glacial acetic acid has been added.

After immersion for half an hour in the solution, the tissues are sufficiently hardened for cutting out the pieces specially required. With a sharp razor a piece less than half an inch long, so as to include three or four complete segments, should be removed from the third quarter of the body. From this transverse sections are to be cut. Another piece should be removed from the anterior end so as to include segments 7 to 16 inclusive ; (of this longitudinal horizontal sections should be cut). These two pieces must be replaced in the solution for twenty-four hours, and then soaked for some hours in 70 per cent. alcohol in which a morsel of camphor has been dissolved. The spirit should be changed at intervals, until finally it remains quite clear when the pieces have been soaking in it. The pieces are then to be stained in a solution of borax carmine for at least two hours, and thereafter soaked in 70 per cent. alcohol rendered acid by a drop of acetic acid ; then they must be soaked successively in 90 per cent. and in absolute alcohol for at least two or three hours. The purpose of these soakings is to replace the water in the tissues by a liquid into which a solvent of paraffin will diffuse. The pieces should now be removed to a narrow test-tube containing about an inch of absolute alcohol. Into this an inch of chloroform should be poured. As the alcohol is lighter than the chloroform it will stand in a column above, and the pieces of worm soaked in the alcohol will also be light enough to float in the upper alcoholic layer. But as the chloroform gradually diffuses into the alcohol it will also diffuse into the tissues of the worm. When this process is complete the pieces of earthworm will, by their own weight, sink to the bottom of the tube. They should then be removed to pure chloroform, and some small fragments of solid paraffin should be dropped in with them. Gentle heat is useful to assist the solution and penetration of the paraffin. For this purpose, the best possible means is to keep the mixture of worm, paraffin, and chloroform in a corked tube in one's waistcoat pocket for a few days. Lastly, the pieces of worm should be picked out and dropped into melted paraffin kept at a temperature under 60° Centigrade, in a hot chamber. If the process recommended here is followed, after an hour in the paraffin the pieces will be completely permeated.

The pieces must now be placed in little paper moulds filled with melted paraffin. Great care must be taken to arrange each piece so that it may be cut exactly in the plane required. When this has been done, as soon as the paraffin is cool enough to be opaque, the mould should be cooled by placing in cold water. Sudden cooling renders it more easy to cut. The blocks when cool must be trimmed to a suitable size, and sections cut with the microtome and placed on a slide in order. The slide should be smeared with a very small quantity of glycerine and albumen, and then placed in a warm chamber until the paraffin has melted. Washing with warm turpentine will dissolve out the paraffin, after which the sections should be mounted in Canada balsam dissolved in chloroform.

The sections must be examined first under a low power in order that the general arrangement of the tissues and organs may be seen. Then the details of structure are to be investigated with a higher power.

Transverse section through the region of the intestine (Fig. 45).

The general shape is round. The dorsal surface is indicated by the typhlosole, the ventral by the nerve cord.

a. **The integument.**—The cuticle (*c*) is thin and structureless: it is usually partly or wholly separated from the underlying epidermis by action of the re-agents.

The epidermis comes next. It is a single layer of columnar cells, with nuclei at their bases. These are either glandular, "goblet cells," or more slender packing cells. The glandular cells secrete the mucus which renders the body of a living worm slimy and aids its movements in its burrow. The packing cells form by secretion the delicate cuticle. A second row of very small cells may be distinguished under this outer layer in specially good preparations. In the region of the clitellum the epidermis cells are separated by small interspaces into which capillaries run, and the whole layer is much thicker.

b. The **setæ** may be seen lodged in sacs which are invaginations of the skin extending deep into the body through both of the muscular layers. Young setæ may be seen lodged within the sacs, and the muscular fibres attached to work the setæ are obvious (*sm*). As the

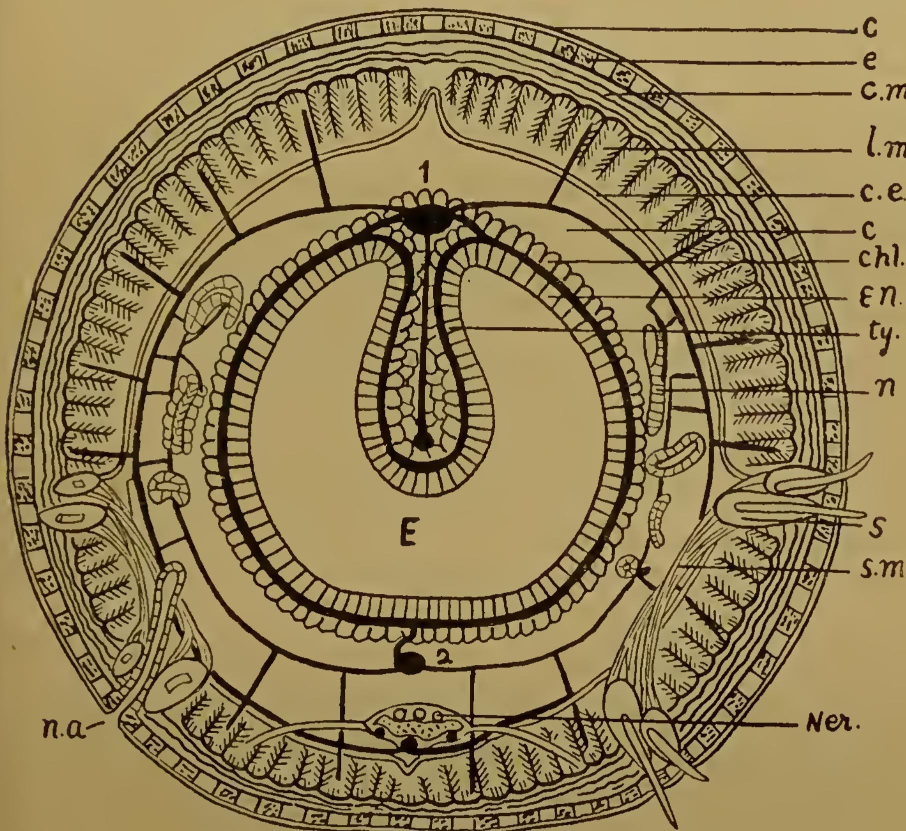

FIG. 45.—Transverse Section through posterior part of Worm. **c.** Cuticle. **e.** Epidermis, the gland cells are light. **c.m.** Circular muscular layer. **l.m.** Longitudinal muscular layer. **c.e.** Cœlomic epithelium. **c.** Cœlome. **chl.** Layer of chloragogen cells covering the intestine and dorsal vessel. **en.** Intestinal epithelium. **ty.** Typhlosole. **n.** Part of nephridial coil. **S.** Seta sac. **s.m.** Muscular apparatus of setæ. **Ner.** Nerve cord; the reference line ends in one of the three giant fibres; the nerve cord is invested with a sheath in which lie the three neural vessels on the ventral side. **n.a.** Nephridial aperture. **E.** Enteron, with typhlosole projecting into cavity. The blood-vessels are in black—**1.** Dorsal vessel. **2.** Ventral vessel.

sections are rarely cut exactly in a vertical plane, the four rows of setæ are not always cut through in a single section.

c. The **muscular layers** of the body wall. These consist of an outer layer, the fibres of which run circularly round the body (*cm*), and an inner layer which is thicker, of fibres running longitudinally (*lm*). The latter, therefore, are cut across in the transverse section. The fibres are elongate columnar bodies marked by delicate longitudinal striæ and embedded in a granular matrix containing nuclei. Betwcen the fibres and between the layers of muscle there is present a quantity of connective tissue, many of the cells of which are pigmented. This connective tissue divides the longitudinal layer into a series of radial longitudinal sheets which in transverse section have a feather-like appearance.

The **cœlome** or body-cavity (*c*) is the wide space between the body-wall and the intestine. It is lined by the cœlomic epithelium, a single layer of cells so delicate that only the nuclei are visible.

d. The **intestine** is the large structure occupying the middle of the section. Its diameter is about half that of the whole body. The **typhlosole** is a prominent fold of the dorsal wall extending down into the intestine and making the actual cavity crescentic. Within this cavity, however one may have attempted to empty the alimentary tract, there is certain to be present *débris* of some kind. The cavity is lined by a single layer of long narrow ciliated cells. Outside this is a thicker layer of muscle fibres and connective tissue. The next outermost coat consists of a ramifying plexus of blood-vessels embedded in chloragogen cells. The blood vessels are recognised by the blood within them which stains deeply. The larger passages of this layer of blood-vessels known as the longitudinal vessels are usually visible. The dorsal blood-vessel lies immediately over the typhlosole, sometimes embedded in chloragogen cells, and the ventral vessel immediately under the intestine; but these two are separate from the plexus, and vessels passing from them into the plexus may have been cut across.

Nephridia.—As these are coiled tubes, in cross section they appear as a number of circular and oblong pieces according to the way in which the plane of the section has cut across the loops. If a successive series of sections has been mounted, these pieces of the nephridia should be traced from section to section until both the funnel and the external orifice have been seen.

The **nerve cord** lies just within the longitudinal muscular layer enclosed in a strong double connective tissue sheath, in which lie three blood-vessels—the subneural on the under side, and the lateral neurals at each side. Within the connective tissue sheath is a thin muscular layer which surrounds the true nervous cord. If the section passes through the middle of a segment, the nerve cord appears to be partly divided by a shallow constriction into two ganglia. The body of the cord or of the ganglia is occupied by delicate nerve fibres which give a granular appearance to the transverse section, and by large nucleated ganglion cells. These are more abundant in the ventral and lateral regions of the cord. Along the dorsal region run three large fibres with thick walls and gelatinous centres, the **giant fibres.** The function of these is unknown, but as they have been traced into nerve cells they are probably part of the nervous apparatus. By some they are supposed to be supporting or skeletal structures. Lateral branches may be seen issuing from the cord running outwards and downwards into the body-wall.

The **septa** are obliquely arranged in the body of the worm, and so in almost every transverse section part of one or more may be cut across. Such appear as very thin sheets of connective tissue with a few muscular fibres running in them.

Longitudinal Horizontal Section through the Genital Organs.—These will differ very much according to the plane from which they are taken, and it is very instructive to study the whole series from the dorsal surface to the ventral surface. This should be done under the low power, as otherwise it is impossible to understand the relative positions of the organs. The most useful are those passing through the levels of the funnels of the genital ducts, although of course it will be extremely improbable that a single section will pass through many of these. As the septa running across the section are very visible, it is not difficult, after a little study and comparison with drawings of the dissected worm, to identify the sections and the organs.

The integument and epidermis running along each side of the oblong section exhibit nothing not seen in transverse sections.

The fibres of the external, or circular, muscular layer, will be seen cut across, while the fibres of the inner, or longitudinal layer, run along the section on each side.

The cœlome will appear as a longitudinal space between the muscles within the muscular layer, and broken up into compartments by the septæ. The plane of the section will probably lie below the intestine except in the region of the gizzard, a small portion of the lower part of which will be visible. Notice the thick muscular wall and the chitinous layer lying within the intestinal epithelium and formed from it as a secretion.

The nephridia will appear much as in the transverse sections.

The septa will exhibit the same structure as in transverse section, and it will be noticed that they are pierced by the blood-vessels, alimentary canal, and genital ducts.

The genital organs occupy positions indicated in Fig. 43, but their relation to each other and to the septæ are more apparent.

After the anatomy of the earthworm has been studied, it is well to consider the parts played by its complicated system of organs in the life of the animal. We saw how hydra differed from a mere colony of cells in that its cells performed their functions for the general benefit of the whole organism. In the more complicated structure of the earthworm this subordination of the parts to the whole is still more marked. Nutrition is now served by an elaborate alimentary canal the various parts of which have distinct functions. The food, which consists of organic matter in the soil, is swallowed by means of the buccal cavity and pharynx; it is ground up in the gizzard, and no doubt digestive juices are poured on it from the cells of the intestine. These certainly ingest from the mass in the gut the nutritious particles, which are in turn handed on to the blood as more elaborated products, and from the blood all the cells of the tissues and organs pick up what nutriment they require. The cells discharge their waste water into the blood, and from it the nitrogenous waste is removed in two ways. The chloragogen cells, which cover the capillaries of the intestine, extract waste matter from the blood and liberate it into the body cavity, whence it escapes by the funnels of the nephridia. Next, the blood capillaries on the middle and inner loops of the post-septal parts of the nephridia afford opportunity for the glandular cells of these tubules to pick out more waste matter, which, along with matter coming in by the funnel, is discharged by the nephridial apertures.

There is in the common earthworm no special organ of respiration. But along with the earthy matter taken into the intestine much air is swallowed, and from this the abundant blood-vessels of the gut absorb oxygen and no doubt return to it carbonic acid, the cells of the gut performing or aiding the transfer. The oxygen combines with the hæmoglobin dissolved in the blood, and is carried to the different tissues and cells of the body, from which again carbonic acid is returned to the gut to be discharged. Associated with the functions of the blood as a carrier of food and of waste matter, of oxygen and carbonic acid, is the fact that it circulates in a closed system of vessels, the contractile hearts and dorsal vessel providing the propelling force.

The reproduction of the earthworm also is complicated. Some of its near allies can reproduce by budding, but although the earthworm has a limited power of reproducing parts accidentally lost, it has not the power of vegetative reproduction. Its normal method is sexual. As it has both male and female organs in the same individual it is a **hermaphrodite.** Cross-fertilisation is secured by a process of copulation. Two worms, with their anterior extremities pointing in opposite directions, apply their genital segments. Spermatozoa are passed from the male apertures of the one into the spermathecæ of the other, the process possibly being reciprocal. After separating, the fertilized worms form cylindrical cocoons of mucus, and, as they wriggle out of these, leave within them eggs from the female apertures, and, from the spermathecæ, spermatozoa that they had received in copulation. The impregnation of the eggs takes place within the cocoon.

CHAPTER XV

VERTEBRATES AND INVERTEBRATES

THE earthworm is only one among a very large number of invertebrate Cœlomata. Some of these, like star-fishes, water-fleas, crabs and lobsters, insects, spiders and scorpions, centipedes, snails and cuttle-fish, are very unlike it. A little reflection on the animals that we all know will convince even those who take no special interest in natural history that the common invertebrates fall into natural groups, each group containing a number of animals all more or less alike. Naturalists, from their greater knowledge of animals, would make more groups and would detect resemblances and differences unapparent to the inexpert. But the least expert would not confuse earthworms with star-fish, or either with insects or snails. These are unlike in almost every feature, and it is in little else than the characters common to all cœlomates that they resemble each other. On the other hand, if we take the cœlomate vertebrates—fishes and amphibians, reptiles, birds and mammals—although there are striking differences between the great groups, yet it is plain that they resemble each other much more closely than do the invertebrate groups. Each have the body divided into head and

trunk, and the latter is continued into a **tail**, short or long. On the ventral surface of the head is the **mouth**; the head contains the **brain**, and carries **nose**, **eyes**, and **ears**. The trunk has never more than **two pairs of appendages**, corresponding to our arms and legs. The body has an internal bony or cartilaginous **skeleton**, consisting of a **skull** or brain-box; a **vertebral column**, the upper part of which is traversed by the **spinal cord**, the great nervous continuation of the brain into the body; a **pectoral girdle**, to which the front pair of limbs are attached; and a **pelvic girdle**, bearing the hind limbs. In all the vertebrates the cavity of the mouth communicates by a straight **œsophagus** with a **stomach**, from which an **intestine** passes to the **anus** at the root of the tail. There opens into the intestine close behind the stomach the duct of a large organ, the **liver**, found in them all; the front part of the alimentary canal, immediately behind the mouth, is specially connected with the function of respiration. In fishes four or five slits on each side of the neck, the **gill-slits**, establish a communication between the inside of the alimentary canal and the exterior, and blood-vessels round about these openings pick up the supply of oxygen for the whole body from the water passing through the slits. The tadpoles of frogs and the unborn young of reptiles and birds and mammals, all possess these slits in the side of the neck opening into the alimentary canal behind the mouth. The blood system of all vertebrates consists of **arteries** and **veins** connected by capillaries, and the blood is always made to circulate by the contractions of a muscular **heart** lying below the alimentary canal in the front part of the body, while the blood itself in them all consists of a colourless fluid, in which are multitudes of white, amœboid corpuscles, and red corpuscles coloured by a pigment, hæmoglobin, which serves to carry the oxygen. All vertebrates have **kidneys** to remove their nitrogenous waste, and the apertures by which the urine is discharged are closely connected with the reproductive apertures, and lie near the anus.

Minuter investigation of the anatomy and of the structure of the cells in the tissues and organs similarly shows the very close resemblance existing among vertebrates. We are led to the conclusion that, while there are many great types or classes of cœlomate invertebrates, of which the earthworm and its allies represent one, there is only one type of vertebrate cœlomate. Vertebrates are larger, and being more familiar with them, we know the differences between them more intimately; but when we compare them with the less familiar differences among the less familiar invertebrates, we find that the vertebrates must be placed in one class, the invertebrates in many classes.

Taking a class such as the vertebrates, with which we are all more or less familiar, it is obvious that there are groups in it which we think of as higher or lower with respect to each other. Thus birds and mammals are higher than reptiles, reptiles than amphibia, amphibia than fish. Below fish, there are a number of small, less familiar animals, such as *Amphioxus*, the lancelet, *Ascidians*, or sea-squirts, and *Balanoglossus*, which continue the vertebrate chain down to animals which, taken by themselves, would pass as very simple invertebrates. A similar condition of things exists among the great invertebrate groups. Common animals like the star-fish and the earthworm, lobsters and crabs, flying insects, snails, and so forth, stand near the top of long series of animals, the lower end of each series consisting usually of inconspicuous simple cœlomate forms. Now to understand properly the resemblances and relationships among these great groups, it is necessary not simply to compare with each other the higher forms, like star-fishes, earthworms, crabs, insects, snails, and vertebrates, but first to trace downwards each separate group to its simplest forms, and then to compare with each other these simplest forms. Such a task forms a great part of the science of comparative anatomy, and within the limits of an elementary course of study it is possible to do little more than to gain an idea of the method by which correct ideas may be gained. Between representatives of two groups of cœlomates like the earthworm and the dog-fish, we must look for little in common besides the simple characters common to all cœlomates.

In Chapter XIII. we have dealt with the common characters of cœlomates; it is now necessary to add a further statement, the evidence for which unfortunately is too long to be given. A particular method of progressive advance of structure is common to all the great groups of cœlomates. The simplest animals in all are least segmented; in many cases they are quite unsegmented, and we may take it that the first or primitive stage of cœlomates is unsegmented. The next stage of advance is shown by a great increase of segmentation, which may affect the whole body or only parts of it, or which may affect different parts or organs in different degrees. The segmentation of the skin may not be exactly the same as that of the cœlome, and the segmentations of these may be different from the segmentations of the nephridia, blood-vessels, genital organs, and so forth. The third stage is a condensation of the segmentation in different regions. The most familiar instance of this is what is called **cephalisation.** Two or more of the anterior segments may be telescoped together at the anterior end to form a complicated and condensed part of the body called the head. Another familiar instance of this process we shall find to be the condensation of a number of nephridia, to form a **kidney.** Like its predecessor, the process of segmentation, this process of condensation may affect separate series of structures in different regions and in different ways, and the result of it is to produce a number of general and misleading resemblances between higher members of different groups.

In the light of these general considerations we may sum up the relations between the earthworm and vertebrates.

The earthworm is one member standing near the head of one of the many groups of invertebrate cœlomates. It has reached the second stage of cœlomate development in that it is very highly segmented, and there is little or no trace of the third stage, the stage of the condensation of segments. The locomotor organs are not limbs, but unjointed, chitinoid setæ implanted in the body-wall. The nervous system consists of a pair of cerebral or prostomial ganglia, and a ganglionated ventral cord showing signs of being two cords closely applied. The excretory organs consist of nephridia opening into the body cavity by a ciliated funnel and to the exterior by an external pore; these nephridia are highly segmented, there being a pair for nearly every somite in the body. The genital organs show much less trace of segmentation.

Vertebrates from fish up to man are the higher representatives of a single group of cœlomates, of which the lower members are inconspicuous cœlomates that reveal their vertebrate affinities only after minute investigation. Vertebrates are highly segmented animals, in which condensation of segments has become an important factor, resulting notably in the formation of a complicated head, and of kidneys formed by the aggregation of many nephridia. There is a well-developed internal skeleton, consisting of a skull with movable jaws, a jointed backbone through the arches of which runs the spinal cord, two pairs of limbs attached to pectoral and pelvic girdles. The central nervous system lies along the dorsal side of the body, and is expanded in front into a brain lying within the head and connected with three great organs of sense—the nose, the eyes, and the ears. The vascular system consists of a closed system of veins, arteries, and capillaries, through which the blood is propelled by a ventrally-placed contractile heart. The blood, in addition to amœboid corpuscles, contains numerous red corpuscles with definite outlines and containing hæmoglobin. Associated with respiration there exists always, either in the adult or in the embryo, a series of paired slits leading from the side of the neck into the alimentary canal behind the mouth. The cœlome is very spacious, and the genital glands arise as paired but unsegmented patches on the dorsal, internal wall of the cœlome.

The type common to the lowest members of the groups of which the earthworm on the one hand and the vertebrates on the other form the highest examples, is a simple unsegmented cœlomate animal, bilaterally symmetrical, with a dorsal and ventral surface and anterior end at which lies the mouth, a posterior end where is the anus. The lower layer of the skin consists of a continuous sheath of nerve cells and fibres, showing a tendency to become concentrated at the anterior end as a brain and in longitudinal bands along the body. These are ventral in the earthworm, dorsal and tubular in the vertebrate group. The cœlome is spacious and contains modified patches, which give rise to the sexual cells. The excretory organs consist of nephridia arranged in one or more pairs, and open into the cœlome by ciliated funnels.

CHAPTER XVI

THE DOG-FISH

THE dog-fish, with sharks and skates, belongs to a group of powerful, predacious, active fishes, known as **Elasmobranchs.** One of their leading characters is that the skeleton is composed of cartilage, strengthened in parts by a gritty deposit of lime, but not turned into true bone. Typically they are inhabitants of salt water, but many of them, in pursuit of prey, enter brackish estuaries or rivers for some distance. The dog-fish found round our coasts belong to several species and genera. *Scyllium canicula*, the larger spotted dog-fish, and *Scyllium catullus*, the lesser spotted dog-fish, are distinguished by the absence of a nictitating membrane, by the small size of their teeth, of which several rows are in use at the same time, each tooth having a long middle cusp and several small lateral cusps. *Acanthias vulgaris*, the spiny dog-fish, is at once recognisable by the strong spine or thorn at each dorsal fin. The teeth are small, and their points are curiously turned aside, so that the inner margin forms the cutting edge. *Mustelus vulgaris*, the common smooth-hound, has a nictitating membrane; the teeth are small, very numerous, and closely packed together, forming a sort of pavement, which is used for crushing rather than for biting.

They are great enemies of fishermen, not only destroying quantities of young fish, but lacerating and damaging edible fish which have been caught in the lines or entangled in the meshes of the nets. They are themselves nearly useless as food, their flesh, like that of many carnivorous animals, being excessively tough and of strong, disagreeable flavour. The sexes are separate, and, as will be described, the males and females can be distinguished by external characters. The eggs are large, and are impregnated within the body of the female. In *Scyllium* they are laid shortly after impregnation, enclosed in a horny capsule the angles of which are produced into long spirally twisted processes which serve to anchor them to seaweed or stones. In some other dog-fish, as in *Mustelus*, the eggs are retained within the body of the mother until the adult shape has been reached, and the young embryo is nourished from the blood of the mother by means of a tuft of blood-vessels not dissimilar to the placenta of mammals. The eggs of these dog-fishes contain little food-yolk ; the eggs of others contain so much that the young dog-fish, even when it has escaped from the capsule and swims about upon its own account, carries the remains of the yolk in a small sac attached by a short stalk to the ventral wall of the abdomen.

The following description applies specially to *Scyllium canicula*, the most common dog-fish, but except in external characters it will serve equally well for the spiny dog-fish or for the smooth hound.

Dog-fish about two feet long are most convenient for dissection. This should be done upon a wooden board with a small raised rim. The characters of the skeleton should be examined on a specimen prepared by immersing a fresh fish in nearly boiling water for a few minutes, and then scraping or brushing the soft parts away. This skeleton must be kept in spirit, as, if allowed to dry, it becomes hopelessly distorted.

External Characters. — The body is elongated, and bilaterally symmetrical. It is broadest about the level of the **pectoral fins**, where it is flattened dorso-ventrally, and ends in front in a rounded blunt snout. The hinder part is compressed laterally, and tapers to the end of the long slender tail, the last two or three inches of which are bent up at an angle. The general colour is a pale grey, spotted on the sides and back with black and brown, and lighter on the ventral surface. Along each side runs a shallow groove, the **lateral line**, and on the head are a number of minute openings arranged symmetrically. These lead into branching tubes, from which mucus can be pressed out, and which, like the lateral line, contain sensory organs.

There are two sets of **fins**, each consisting of flattened outgrowths supported by an internal cartilaginous skeleton. The **median** or **unpaired fins** consist of—(1) **Dorsal fins,** a large anterior fin about the middle of the length of the body, and a small posterior fin some distance behind. (2) A **ventral fin,** opposite the interval between the dorsals. (3) A **caudal fin,** forming a fringe round the tail, cut off sharply at the tip, and on the ventral side divided into a small posterior and a large anterior lobe. These caudal fins give the tail of elasmobranch fishes a characteristic shape known as **heterocercal,** and notably different from the tail of bony fishes like the herring or salmon, in which the tail fin is symmetrical above and below the middle line.

The **paired fins** correspond to the fore and hind limbs of higher animals. Those of the **pectoral pair** project out from the ventral side of the body behind the head. The **pelvic fins** are much smaller, and are placed on the ventral side of the body some distance behind the front pair. Their inner borders are close together, and are fused in males. In the males, also, close to the pelvic fins, and developed from their inner borders, are a pair of stout rounded processes, pointed at the ends and projecting backwards. These are copulating organs, called **claspers**, and along their inner dorsal edge a deep groove runs into a blind sac under the skin of the ventral surface.

The tail fin is the chief organ of locomotion in fishes. The median fins serve chiefly to preserve the balance of the fish ; the paired fins assist in balancing, and are used also to turn and guide the motions of the fish.

External Apertures.—The **mouth** is a large, curved slit extending across the ventral side of the body a short distance from the anterior end. The **cloacal aperture** is also median, and lies on the ventral side between the pelvic fins. It is the external opening of a small chamber, the **cloaca**, into which open the rectum, the ducts of the kidneys and of the genital organs.

The **nostrils** are a pair of large circular apertures on the ventral side of the head in front of the mouth, and connected with that by wide grooves covered by flaps of skin.

The **spiracles** are a smaller pair of apertures on the dorsal side of the head just behind the eyes; they open into the cavity of the mouth.

The **gill-slits** are a set of five vertical slits on each side of the neck, beginning immediately below and behind the spiracle, which itself is in reality an anterior gill-slit. Each gill-slit communicates with the pharynx immediately behind the mouth-cavity, and during life water taken in by the mouth is passed out through the gill-slits.

The **abdominal pores** are a pair of minute apertures, lying one on each side of the cloaca. They open into the cœlome.

The Scales and Teeth.—The whole external surface of the body is covered by small, sharp-pointed scales, which may be felt by passing the finger from behind forwards along the surface. Where the skin bends over to form the lining cavity of the mouth the scales covering the jaws are much enlarged to form teeth. The spines of the piked dog-fish are enlarged scales. A small piece of the skin of the common dog-fish should be boiled in caustic potash solution to dissolve away the fleshy matter and isolate the scales. These, examined under the microscope in glycerine, may be seen to consist of a four-lobed bony base which was embedded in the skin, and a backwardly-directed bony spine, tipped with enamel.

The Skeleton.—As the skeletons of all vertebrates are built upon the same ground-plan, and as the skeleton of the dog-fish exhibits a comparatively simple condition of this, it is of great importance to grasp the general features. Even in a soft-bodied animal like the earth-worm there is present a considerable amount of connective tissue, forming partitions and supporting-membranes between the muscle-layers and muscle-bundles. Such a tissue is really in function **skeletal**, or supporting; and very early in the development of all vertebrates a considerable amount of skeletal tissue appears in the shape of connective-tissue cells, which migrate in between the organs and layers and form a general supporting framework. But in the case of the vertebrates the name skeleton is specially associated with supporting structures developed in connection with the special features of vertebrate structure. These are, first, the **skull**, which supports and surrounds the brain; second, the **vertebral column**, or backbone, which lies immediately under the spinal cord or dorsal nervous tube; third, the **visceral arches**, which support the gill-slits; fourth, **the skeleton of the front and hind pairs of limbs.** But in addition to this specialisation of skeletal tissue in these different places, changes in the nature of the skeletal tissue occur. The connective tissue may be replaced by **cartilage**, and the cartilage may be strengthened by the deposition of calcareous particles. The skeleton of the dog-fish does not get beyond this condition, but in higher animals the cartilage may be replaced by **true bone**. True bone may also be formed directly, in connective-tissue membranes, as happens in the case of the bony plates which form the bases of the scales and teeth of the dog-fish. Bony structures which are first laid down in cartilage are called **cartilage bones**, and most of the bones of higher animals are instances of this mode of formation. Bones which are laid down directly in membrane are called **membrane bones**, and these form a much smaller part of the skeleton of higher animals.

The Vertebral Column or Backbone.—In a dog-fish embryo there is formed from the dorsal wall of the alimentary canal a long gelatinous rod which lies between the alimentary canal and the nervous system, extending from below the hind-part of the brain to the posterior end of the body. This rod is the **notochord**, and is the foundation of the backbone in all vertebrates and the only representative

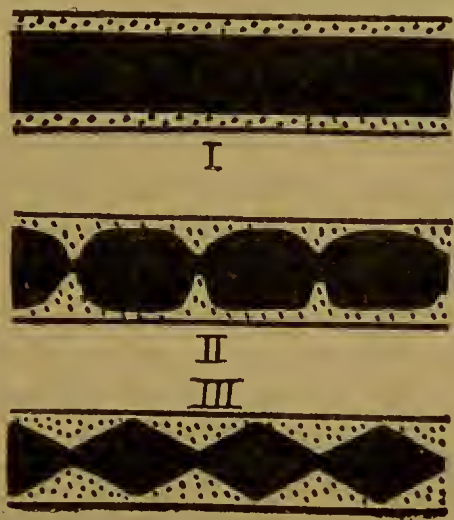

FIG. 46.—Longitudinal vertical section of three stages of development of Vertebræ from the cartilaginous sheath of the Notochord. Cartilage, dotted; chord, black. I. Continuous sheath, chord unconstricted. II. Sheath segmentally thickened, notochord constricted. III. Further stage; the segmental thickenings have nearly met to form biconcave vertebræ.

of the backbone in the members of the vertebrate group lower than fishes. In the dog-fish and all higher animals, the notochord very quickly is surrounded by a sheath of wandering, skeleton-forming cells, such as form the whole skeleton in simpler animals, and it is from this sheath that the actual backbone is formed by a series of segmentally-arranged thickenings (Fig. 46). In the dog-fish the sheath of the notochord is cartilaginous, and its anterior part gives rise to the posterior part of the skull, while in the body it becomes divided transversely into segments which are the **centra**, or bodies of the vertebræ. Above the centra, **neural arches** grow and surround and protect the nervous tube, while below them **hæmal arches** and **ribs** partly enclose the body-cavity.

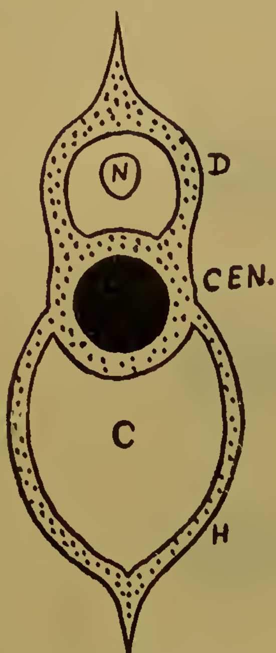

FIG. 47.—Diagram of Caudal Vertebra. Notochord, black; cartilage, dotted. **CEN.** Centrum. **D.** Dorsal arch, containing **N.** spinal cord. **H.** Hæmal arch containing **C.** cœlome.

By this process of segmentation the backbone, consisting of a series of vertebræ, is formed. The simplest vertebræ are seen in the tail (Fig. 47). Each consists of a **centrum**, through which runs the notochord, a **dorsal arch**, with a dorsal spine above, forming the neural canal through which runs the nerve tube, and a ventral or **hæmal arch**, also with a spine, enclosing the body cavity, which in the region of the tail is minute. Further forward in the body the hæmal arches are not complete; the processes which in the tail meet to form these arches stand out at right-angles to the line of the backbone and are termed **transverse processes.** To the end of each transverse process a short cartilaginous **rib** is attached.

To understand the structure of the backbone it is necessary to cut transverse, longitudinal, and horizontal sections through various parts of it. It will then be seen that the notochord runs continuously through the whole column, but that it is much constricted where it passes through the middle of the centra, and expanded between the centra. Thus, if the column be cut through between two vertebræ, the soft notochord may easily be brushed out from the cut ends, and it then appears that the ends of the cartilaginous vertebræ are deeply hollowed out where they meet each other. Such vertebræ are known as **biconcave**, and examples of them are familiar to us all in the backbones of common bony fish like herrings or salmon. The successive centra are united to each other by **intervertebral discs** of connective tissue. The whole of the cartilage of the centra is hardened by deposits of lime, but the deposit is denser towards the inside. In many cartilaginous fish the highly-calcified portions of the centra form, in transverse section, a regular, usually X-shaped, pattern.

The **neural arches** (Fig. 48) are complicated. Their bases are formed by the neural processes, blunt pieces projecting from the centra at each side. Firmly attached to each neural process is a **vertebral neural plate**, considerably narrower than the neural process and the centrum, and notched at its posterior border for the passage of the ventral root of the spinal nerve (Fig. 48. *e*). The arches are completed above by short **neural spines** (Fig. 48. *h*). But these are not arranged so as to give one for each centrum, but, with the exception of occasional irregularities, there are two spines for each centrum, and these meet each other opposite the middle of the centrum. Finally, there are irregular hexagonal plates, the **intervertebral neural plates** (Fig. 48 *f*), wedged in between the vertebral neural plates opposite the intervertebral intervals. The posterior border of each is notched for the dorsal roots of the spinal nerves (Fig. 48 *h*).

The **skull** of the dogfish remains cartilaginous throughout life. It is a shallow oblong box deeply scooped at the sides where the eyes are lodged, open behind, where the

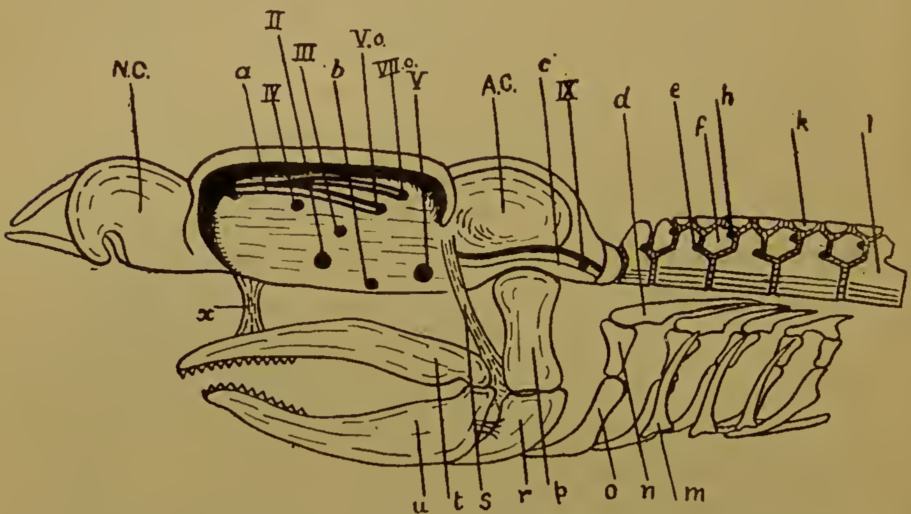

FIG. 48.—Lateral view of Skull of Dog-fish. **N.C.** Nasal capsule. **A.C.** Auditory capsule. **a.** Orbital grooves lodging ophthalmic branches of fifth and seventh nerves. **b.** Inter-orbital canal. **c.** Post-orbital groove. **f.** Inter-vertebral neural plate. **k.** Neural spine. **l.** Centrum with vertebral neural plate above it. **d.** Pharyngo-branchial. **m.** Extra-branchial. **n.** Epibranchial. **o.** Ceratobranchial. **p.** Hyomandibular. **r.** Cerato-hyal. **s.** Prespiracular ligament. **t.** Upper jaw. **u.** Lower jaw. **x.** Ethmopalatine ligament. **Nerve Foramina.** **II.** Optic. **III.** Third nerve. **IV.** Fourth nerve. **V.** Main branches of fifth and seventh, and the sixth nerve. **V°.** Ophthalmic branch of fifth nerve. **VII°.** Ophthalmic branch of seventh. **IX.** Ninth nerve. **e.** Ventral root of spinal nerve. **h.** Dorsal root.

brain passes into the spinal cord, incomplete and roofed over only by the outer skin in two regions above. The cartilaginous capsules containing the nasal organs are wedged into it at each side in front, and the similar capsules containing the organs of hearing are wedged in at each side behind. It articulates with the vertebral column behind, and the **jaws** and **gill-arches** are suspended below it.

The ventral surface of the skull is formed of a long flat unsegmented plate of cartilage called the **basi-cranium.** The notochord lies embedded in the posterior part of this. On each side of it there project backwards two rounded **occipital condyles** which articulate with the centrum of the anterior vertebra. In front, the basi-cranium terminates in a narrow pointed bar of cartilage lying between the olfactory capsules.

The dorsal surface of the skull shows in front the thin-walled roofs of the **olfactory capsules.** These are separated by the **internasal septum,** a thin wall of cartilage. The apertures of the nasal capsules are on the ventral surface, but are partly filled by a number of slender nasal cartilages. From each olfactory capsule a bar of cartilage runs forwards, downwards, and inwards, until the two meet at a point with the anterior end of the base of the skull. This three-legged projecting piece of the skull is termed the rostrum. Behind the rostrum and partly between the nasal capsules is the **anterior fontanelle.** This is an incomplete portion of the roof of the cartilaginous brain-box. During life it is closed by a delicate connective tissue roof to which the **pineal body** is attached, and which is protected outside only by the outer skin. Behind the nasal capsules the sides of the roof extend as thickened ridges, the **supra-orbital crests,** which overhang the orbits like eaves. On the roof of the skull, behind and to the outer side of the anterior fontanelle, are a pair of small apertures, the foramina for the ophthalmic nerves. Through them pass branches of the fifth and seventh nerves in their course from the orbit to be distributed to the surface of the olfactory capsules. Behind the anterior fontanelle the surface of the skull widens rather suddenly in the region of the auditory capsules. Between these is a depression in which there lie two small apertures, each of which is the entrance to a canal, the **aqueductus vestibuli**, leading into the internal ear.

Between the nasal and auditory capsules the side of the skull is occupied by the **orbit**, a large oval concavity in which lies the eyeball and its muscles, and a large orbital blood sinus. The **orbito-nasal foramen** is a small round hole just within the orbit at its anterior inferior angle; through it the veins of the forepart of the head and of the snout pass to the orbital sinus.

The aperture of the **inter-orbital canal** is a small round hole, the nearest to the lower border of several lying in the posterior part of the orbit. The canal passes through the base of the skull and by means of it the orbital sinuses of the two sides are in communication. From the hinder end of the orbit a deep **post-orbital** groove passes back near the lower margin of the skull. It lodges a large venous sinus through which the blood from the orbital sinus passes to the anterior cardinal sinus. Under this groove is a large concave depression, the articular surface for the **hyomandibular cartilage**.

To see the posterior face of the skull it must be disarticulated from the vertebral column. The **foramen magnum** is the large round hole by which the brain communicates with the spinal cord. Below it, in the middle line, lies the notochord, and on each side of this lie the occipital condyles, two rounded prominences which articulate with the first vertebra. The posterior face of the skull corresponds to a vertebra : the lower part containing the notochord and bearing the condyles, represents the centrum ; the ring of cartilage surrounding the foramen magnum represents the neural arch.

During the development of the skull, holes are left in the cartilage through which the cranial nerves pass out from the brain. The position of these **nerve foramina** is important, and should be studied both in the prepared skull and in connection with the dissection of the nerves. They are paired, and those of one side only are described.

I. The foramen of the **olfactory nerve** is a large aperture in the posterior wall of the nasal capsule, which, during life, is closed by a fenestrated membrane.

II. The foramen for the **optic nerve** is the most anterior of the large holes in the hinder part of the orbit. It lies near the lower border, almost exactly in the middle of the orbit.

III. The foramen for the **third nerve** is a small hole in the orbit a little above the optic foramen, and half way between it and the posterior end of the orbit.

IV. The foramen for the **fourth nerve** is a small hole near the dorsal edge of the orbit almost vertically above the optic foramen.

V., VI., and VII. The foramen for the principal branches of the fifth and seventh nerves, and for the sixth nerve, is a large hole in line with the optic foramen, near the posterior edge of the orbit. The ophthalmic branches of the fifth and seventh nerves leave the skull by separate holes ; two grooves run along the upper part of the orbit ; the lower groove ends behind in a small hole which is the foramen for the ophthalmic branch of the fifth nerve ; the upper groove similarly ends in the foramen for the ophthalmic branch of the seventh. These grooves meet in front and terminate in a hole by which the ophthalmic branches leave the orbit to emerge upon the surface of the skull.

VIII. The **auditory** nerve enters the auditory capsule through a hole in its inner wall.

IX. The foramen for the **glossopharyngeal** nerve is at the hinder end of the post-orbital groove.

X. The foramen for the **pneumogastric** or **vagus** nerve is at the side of the foramen magnum, below and to the inner side of the posterior end of the auditory capsule.

THE VISCERAL ARCHES.

In the embryo dog-fish, soon after the gill-slits have been formed, a series of cartilaginous hoops or arches encircling the ventral side appears between them and gives rise to the **jaws**, and to the **hyoid** and **branchial arches**. The first arch gives rise to the lower jaw, from which the upper jaw is an outgrowth. In front of this is the mouth, behind it the two spiracles. The second arch forms the **hyoid**, behind which is the first gill-cleft. Then follow five branchial arches with the remaining four gill-clefts between them, so that each gill-slit has an arch in front and behind.

The first, or **mandibular arch**, is greatly modified in the adult condition. The upper part of the arch at each side is represented by the **prespiracular ligament**, a strong fibrous band containing a nodule of cartilage. This band is attached above to the anterior border of the auditory capsule, and below to a ligament uniting the angles of the upper and lower jaws to the hyomandibular bar. The lower parts of the first bar are represented by two flattened bars of cartilage which are united by ligament in front and form the lower jaw, which, for the greater part of its dorsal border, bears teeth. The upper jaw is formed of two similar curved bars which are united by ligament to each other in front, and which are firmly attached by ligaments to the front part of the base of the skull betwen the orbits and the nasal capsules. The posterior ends of the upper jaw are attached by ligament to the lower jaw and to the hyomandibular bar. The upper and lower jaws move on each other by rounded articular surfaces. The greater part of the lower border of the upper jaw bears teeth. The second, or **hyoidean arch**, consists of a pair of rods united to the skull above, and with their ventral ends connected by a median plate of cartilage. The upper end of each side consists of a stout bar of cartilage, the **hyomandibular**, which articulates with a concave surface on the side of the skull near the hinder end and immediately below the post-orbital groove. This bar is called the **suspensorium**, because it is the chief means by which the jaws are attached to the skull. The outer end of the hyomandibular articulates with the second part of the arch, the **ceratohyal**. This is a slender bar of cartilage running forwards and inwards on the floor of the mouth. The posterior faces of these two parts of the second arch bear **gill-rays**, cartilaginous bars which support the gills. The **basi-hyal** is a broad ventral plate of cartilage which projects forwards on the floor of the mouth and connects the inner and lower ends of the cerato-hyals.

The five succeeding **branchial arches** diminish in size from before backwards. Each is divided into four segments at each side. The **pharyngobranchials** form the dorsal elements. The anterior three are connected by ligaments with their fellows of the other side. The posterior two of each side are small and are fused. The **epibranchials** come next, and form the outermost pieces of the arches. The **ceratobranchials** form the greater portion of the arches on the ventral surface. The **hypobranchials**, which are turned forwards and connected with the hyoid in the first arch and are absent in the last, form the ventral ends of the arches.

The **basibranchial** is a median plate in the posterior part of the ventral floor of the pharynx, connected with the hypobranchials of the third and fourth arches, and with the ceratobranchials of the fifth.

Gill-rays are borne by the ceratobranchials, and by all but the hindmost epibranchials.

The exact shape and modes of fusion of the different branchial elements in the dog-fish are of no importance unless one is studying the anatomy of a number of different fishes. For while the elements of the branchial arches are similar in most fishes, the details of arrangement and shape differ widely.

The **extra-branchials** are three pairs of curved rods lying outside the third, fourth, and fifth branchial arches.

SKELETON OF THE FINS.

The **pectoral girdle** is a flattened hoop of cartilage lying on the ventral surface immediately under the heart, its anterior dorsal surface being hollowed out to receive the ventricle. The outer border of each side bears three articular facets closely set together, to which the cartilages of the fin are attached. These articular surfaces divide the girdle into a median ventral portion, which may be called the **coracoid,** and upper free ends which extend towards the backbone but do not meet it, and which may be called the **scapular** portions.

The skeleton of the fin consists of three **basal cartilages** articulating with the girdle, and a number of closely-set

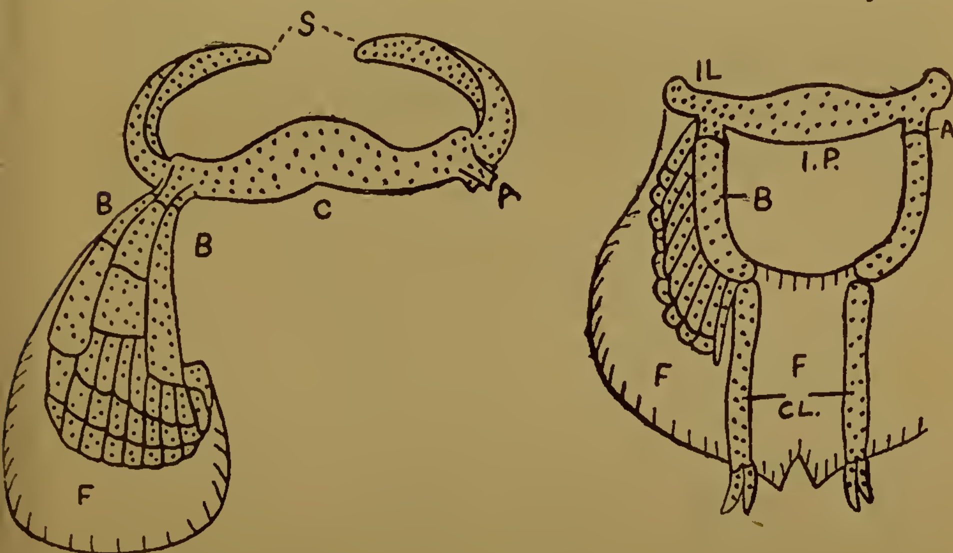

FIG. 49.—Pectoral and Pelvic Girdles of Dog-fish with Fins; Cartilage dotted. Pectoral Girdle: **S.** Scapular region. **C.** Coracoid regions united ventrally. **A.** Acetabulum. **B.** Three basal cartilages. **F.** Fin. Pelvic Girdle: **IL.** Iliac region. **I. P.** Ischiopubic regions united ventrally. **A.** Acetabulum. **B.** Basal cartilage. **CL.** Claspers. **F. F.** Fins.

cartilaginous **fin-rays** radiating out from the ends of the basal cartilages, and bearing terminal horny rays.

The pelvic girdle is much smaller than the pectoral girdle, and is placed a short distance in front of the cloaca. It is divided into upper and lower regions by the articular surface for the fins. The upper or **iliac** portions are excessively short, and have hardly any curve upwards. The ventral or **ischio-pubic** portions, like the coracoid regions of the anterior girdle, are fused together in the middle line.

The skeleton of the pelvic fins consists of a stout curved basal rod articulating with the girdle at one end and lying on the inner edge of the fin. On its outer surface it bears a number of cartilaginous fin-rays, the anterior one or two of which may articulate directly with the pelvic girdle.

In the male a stout jointed rod of cartilage, the skeleton of the **clasper**, articulates with the posterior end of the basal rod of each fin.

DISSECTION OF THE VISCERA.

The dog-fish must be laid on its back on a dissecting board, and pinned down through the fins. The pectoral and pelvic girdles can be felt through the skin, each girdle being situated a short distance in front of the pair of fins attached to it. The abdominal cavity must be opened by a median ventral incision through the skin and underlying muscles, reaching from behind the pectoral girdle to the pelvic girdle. Incisions at right angles to the first cut must be made as close as possible to the posterior margin of the pectoral girdle, and the flaps so formed must be pinned back so as to expose the cavity widely. The pelvic girdle must be cut through in the middle line, and the incision continued, a little to the right of the middle line, to the level of the cloacal aperture. This is the most convenient method of dissecting the dog-fish, but if the student has opportunity it is useful to dissect a second fish from the right or left side.

The abdominal cavity, in which are contained the greater part of the viscera, is the chief division of the cœlome in the adult, and the only part in the posterior division of the body. In front, the cœlome is represented by the **pericardium**, which contains the heart, and the two parts of the cœlome communicate by a small median **pericardio-cœlomic canal**. Posteriorly, the body cavity usually communicates with the exterior by the small **abdominal pores**, but these occasionally are blind sacs, and are not known to be of any physiological importance. The cœlome, then, is practically a closed cavity, and unlike the body-cavity of the worm, contains only a very small quantity of serous fluid, devoid of corpuscles. The cavity is lined internally by the **peritoneum**, a smooth glistening membrane. The viscera in reality are outside the peritoneum; they bulge into it, as a man leaning against the outside of a tent bulges into the interior of the tent, pushing the canvas wall before him. In the case of the cœlome, however, the bulging goes on so far that the folds of the peritoneum in which the organs lie meet above the organs. Viewed from the inside therefore, when one has opened the cavity as directed, the organs seem suspended in the cœlome by delicate folds. These folds form the **mesentery** which is naturally double as it is formed by the applied walls of the peritoneum meeting above the inpushed organs. The blood-vessels also lie outside the cœlome, and their branches to the organs run down between the walls which form the mesentery. The peritoneum is very thin and transparent, and cannot be seen over many of the organs, except in microscopic preparations, while over the genital organs and kidneys it cannot be traced as a separate layer, as a large part of these, as in the case of the earthworm, is formed from the cœlomic wall itself.

The **alimentary canal** is a tube nearly straight from the mouth to the anus. The mouth and pharynx will be considered later. The **œsophagus** is a wide tube which enters the abdominal cavity at the anterior end, and is suspended in it by the mesentery which is incomplete at intervals.

The anterior end passes at once into the wider U shaped **stomach**, which is partly concealed by the large brown **liver**. The proximal limb of the stomach, into which the œsophagus opens, passes nearly to the posterior end of the abdomen, and then bends round sharply to form the shorter, narrower, distal limb which runs forwards and narrows till it passes into the **intestine**, from which it is separated by a **pyloric** thickening. The intestine runs straight back to the cloaca. The middle and longest part of the intestine is very wide and is marked spirally by blood-vessels which correspond to the line of attachment of the spiral valve, an internal fold. The posterior end is narrower and is called the **rectum**. The intestine should be slit open along its length and washed out. The **spiral valve** is then seen as a membranous fold extending far into the cavity of the intestine and running spirally round it for several turns. Like the typhlosole of the earthworm, it is an arrangement which increases the absorbtive surface of the intestine.

The **liver** is a large, solid, brown organ, consisting of right and left lobes united in front, and extending backwards nearly to the posterior end of the abdomen. Anteriorly, it is attached to the wall of the cœlome by a median suspensory ligament. It is an important organ present in all vertebrates, and has several distinct functions. First, it serves as a storehouse of reserve material which is drawn upon by the body in times of need. The nutritive value of the material stored up in the liver is familiar from the use in medicine of cod-liver oil. Next, it is an organ which secretes nitrogenous waste matter. In this respect it may be compared with the chloragogen cells covering the intestine of the earthworm. In the case of the liver, however, the waste matter is first separated from the blood and then returned to it in the form of urea or of a closely allied, nitrogenous substance, and is finally removed from the body by the kidneys. Thirdly, the liver is a digestive gland which secretes the **bile.**

The **gall-bladder** is a large, thin-walled sac, embedded in the left lobe of the liver near its anterior end. It receives several short ducts from the liver, by which part of the secretion of bile reaches it. The **bile duct** is a stout tube which leaves the gall-bladder, afterwards receiving several short ducts from the lobes of the liver, and running back in the mesentery to enter the intestine at the commencement of the spiral valve.

The **pancreas** is a whitish, laterally compressed organ occupying the angle between the intestine and the stomach, behind the pylorus. The digestive juice formed in it leaves it by the **pancreatic duct,** which, starting from the ventral side of the pancreas, runs into the ventral wall of the intestine, and about half an inch from where it enters the wall, opens into the cavity of the intestine, beside the attachment of the spiral valve.

The **rectal gland** is a dark-red, thick-walled, tubular gland lying in the abdominal cavity above the rectum. A narrow duct leaves its posterior end and opens into the rectum. The function of this gland is not known, and it is not found in the higher vertebrates.

The **spleen** is a dark-red body attached to the posterior part of the loop of the stomach, and has a narrow lobe running forwards, closely applied to the distal limb of the stomach. It is a ductless gland present in all vertebrates. It receives a very rich supply of blood, and belongs to the vascular system rather than to the alimentary system, its chief function probably being the destruction of used-up and damaged red corpuscles.

The respiratory system. The gills must be examined by slitting open the gill-slits by cuts extending above and below the external openings. Each slit leads into a wider and longer cavity, in which the highly vascular gill-filaments hang from the walls. The inner end of the cavity communicates with the internal cavity of the pharynx by apertures guarded by cartilaginous processes of the gill-bars which prevent the entrance of food with the water. The gills are folds of the mucous membrane; they are borne on the posterior surface of the hyoid arch and on the anterior and posterior surfaces of the four following arches, but not on the last arch. The anterior wall of the spiracle bears a rudimentary gill, called the **pseudobranch**.

THE CIRCULATORY SYSTEM.

The **heart** is a muscular tube bent on itself, and lying within the pericardial cavity in the ventral anterior region of the body between the gills. The contractions of the heart drive the blood forwards through the anterior end into branches which lead to the gills. In these the blood discharges carbonic acid into the water passing out through the slits, and takes up oxygen. The blood, thus purified, leaves the gills by vessels which meet to form a large median vessel, the **systemic** or **dorsal aorta**, which runs along the body above the alimentary canal, and gives off branches to the different organs. In these, the blood gives up oxygen to the cells of the tissues and receives carbonic acid, and then leaves them by small vessels which meet to form the large thin walled **venous sinuses**, which lead it back to the heart, entering by the posterior end. The circulatory system is therefore a closed system of tubes through which the shocks given by the contractions of the heart are sufficient to keep the blood moving. The arteries, or tubes leading from the heart to the gills, and from these through the systemic aorta and its branches to the tissues, are narrow and thick-walled, and therefore very little of the momentum given by the beats of the heart is lost. The veins are much roomier cavities through which the blood percolates more sluggishly on its returning course. In addition to carrying oxygen and carbonic acid and so serving the **respiration** of the tissues, the blood serves the **nutrition** of the tissues. It picks up nutritive materials from the intestine, and allows the cells of the tissues to absorb what they require from these. It also serves **excretion** by receiving nitrogenous waste from the tissues, and carrying it to the liver and the kidneys. The exact share of these organs in the formation of urea, in the case of the dog-fish, is unknown ; but between them, urea is separated from the blood and is discharged from the body by the kidneys. The blood consists of a fluid **plasma** containing **white** and **red corpuscles**. The white corpuscles are amœboid cells, one important function of which is the ingestion and destruction of microbes and other foreign bodies which have found their way into the system. The white corpuscles can pass through the walls of the vessels, and so migrate into the tissues. The red corpuscles are oval, nucleated cells tinged red with hæmoglobin. Their chief function is to carry oxygen from the gills to the tissues.

The pericardial cavity should be opened by an incision in the mid-ventral line in front of the pectoral girdle. Care must be taken not to injure the heart, which lies within it. When it has been opened, the ventral wall should be cut away so as to expose the heart fully, a small piece being also cut out of the middle of the pectoral girdle. The **ventricle,** a thick-walled globular tube, is the most ventral and conspicuous part of the heart. Passing forwards from this to the front wall of the pericardium, through which it passes, is the **conus arteriosus,** which narrows as it becomes the **cardiac aorta.** The **auricle** is a thin-walled sac occupying the dorsal part of the pericardial cavity, and running forwards from its opening into the ventricle. It slightly overlaps the ventricle at the sides. The **sinus venosus** is the most posterior part of the heart, and is a thin-walled tube, running from above the front end of the auricle to the posterior wall of the pericardium, through which it passes and then expands again to form the extra-pericardial part of the sinus. Above the sinus venosus, in the posterior wall of the pericardium, is the opening of the **pericardio-cœlomic canal,** which opens into the abdominal cavity about an inch behind the pericardium.

After the blood vessels have been dissected, the heart should be removed along with the pericardium and part of the floor of the mouth, and cut open, washed out and examined carefully. The ventricle must be opened by cutting away the lower part of its wall ; it is seen to be thick-walled and muscular, and to contain only a small globular cavity. The cavity of the conus arteriosus, opened by a ventral slit prolonged from the opening made into the ventricle, is seen to be guarded by a set of three valves near the ventricle, and by another set of three slightly in front. These are arranged so as to

FIG. 50.—Heart of Dog-fish. To the left, ventral view, pericardium opened: pericardial cavity, black. **BA**. Conus arteriosus. **A**. Auricle. **V**. Ventricle. **SV**. Sinus venosus within pericardium. **SV**[1]. Sinus venosus outside pericardium. **L**. Liver. To the right, longitudinal vertical section: cavity of pericardium and of heart, black. **P**. Pericardium. **PC**. Canal from pericardium to cœlome. **A**. Conus arteriosus, at the root of which are two pairs of valves; this leads into thick-walled ventricle (**V** wall), which is open above to thin-walled auricle which communicates behind with sinus venosus (**SV**[1]) passing outside pericardium.

prevent the regurgitation of the blood into the ventricle. The opening of the ventricle into the auricle is a transverse slit in the posterior part of the roof of the ventricle, guarded by a two-lipped valve, which prevents blood from passing back again to the auricle during the contraction of the ventricle. The cavity of the auricle must be opened by cutting through the anterior and lateral borders, and turning back the flap thus made of its floor. The walls are thin, and possess radiating muscular bands,

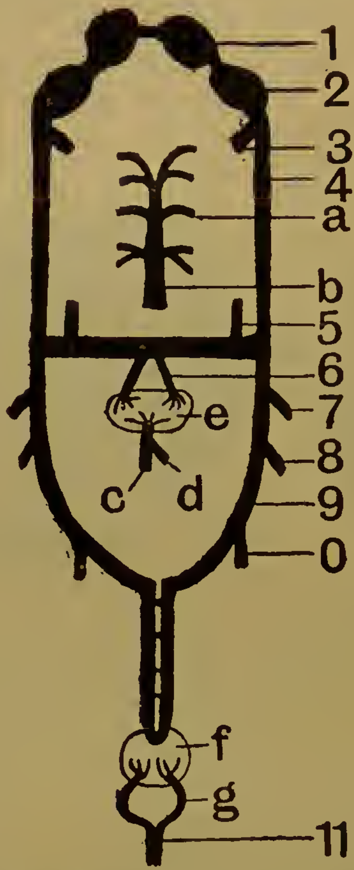

FIG. 51.—Diagram of Venous Blood Channels in Dog-fish. 1. Anterior orbital sinus communicating with its fellow of the other side by inter-orbital canal. 2. Post-orbital sinus. 3. Hyoid sinus. 4. Anterior cardinal sinus. 5. Jugular sinus. Between the two lie the Cuvierian sinuses, meeting in the middle line. 6. Hepatic sinus. 7. Subclavian vein. 8. Lateral vein. 9. Posterior cardinal sinus; the two are in close connection behind and pass back to kidney. 0. Genital sinus. 11. Caudal vein. g. Renal portal vein. f. Kidney. e. Liver. c. Intestinal portal vein. d. Splenic portal vein. b. Cardiac aorta. a. Afferent branchial arteries.

which cause the contraction by which the blood is forced into the ventricle. The aperture into the sinus venosus is a vertical slit in the posterior wall ; the cavity of this is spacious, and the walls have a feeble network of muscles. It opens by a wide aperture into the extra-pericardial part of the sinus, and receives the small cardiac sinus, by which blood is returned from the tissues of the heart itself.

The **veins** are spacious thin-walled channels forming irregular sinuses rather than vessels. They must be dissected by opening the ventral wall of the sinus venosus, washing out the contained blood, passing seekers into the apertures of the sinuses, and then slitting open their ventral walls and washing out the contained blood.

The **hepatic sinuses** open into the sinus venosus by a pair of apertures near the dorsal part of the posterior wall on each side of the middle line. They return the blood from the liver, and lie close together between the liver and the pericardium.

The **Cuvierian sinuses** are the lateral continuations of the extrapericardial part of the sinus venosus. They curve upwards, lying closely applied to the inner side of the posterior branchial arches.

The **inferior jugular sinus** at each side opens into the middle of the Cuvierian sinus. They run forwards along the outer wall of the pericardium, and in the floor of the mouth.

The **great anterior cardinal sinus** of each side opens into the dorsal end of the Cuvierian sinus by a small hole, guarded by a valve with two flaps. Each extends forwards as a wide, very irregular space lying above the gill arches. At the level of the hyoid arch each receives a **hyoidean sinus**, a narrower venous channel which runs down a groove in the hyo-mandibular cartilage until it meets the jugular sinus.

The **post-orbital sinus** is a narrower channel at each side, which runs from the anterior end of the anterior sinus, over the spiracle, under the side of the auditory capsule, to open into the very large **orbital sinus**, which surrounds the eye and communicates with its fellow of the other side through the **interorbital canal.**

The **posterior cardinal sinus** of each side extends from the summit of the Cuvierian sinus as a sac, nearly an inch in width, lying first at the side and then above the alimentary canal. It communicates by many small openings with its fellow of the other side. When they reach the kidneys, the sinuses narrow considerably, and pass backwards between them, giving off numerous **renal veins.** Into each sinus opens first the **subclavian vein,** which returns blood from the region of the pectoral fin; then the **lateral vein,** which returns blood from the side of the body wall; and lastly, the **genital sinus,** which surrounds the genital organs.

The liver and the kidneys are organs which receive not only supplies of arterial blood like all the organs and tissues, but a special supply of blood on account of their special functions. For the latter purpose, both liver and kidneys receive a special supply of blood taken to them by veins. These arrangements are called **portal systems,** and their distinctive feature is that veins break up into small vessels which ramify through the tissues in question; whereas veins in other cases do not break up into smaller vessels on their way from the organs to the heart, their special business, so to speak, being to take back the impure blood to the heart without loitering by the way.

The **hepatic portal vein** is formed by the union of a vein from the spleen with a large vein which returns the blood from the intestine. The portal vein breaks up into a series of irregular capillaries in the liver.

The blood from the tail is returned by a median **caudal vein**, which runs through the hæmal arches. Just behind the kidneys it divides into two branches, which, after receiving small veins from the body wall, run along the dorsal surfaces of the right and left kidneys, and gradually break up into vessels which pass into the kidneys.

The arteries, on account of their smaller calibre and thicker walls, can be dissected without opening them; but it is convenient to inject them from the conus arteriosus, and from the caudal artery.

The **aortic arches**, through which the venous blood is pumped from the conus arteriosus, are termed the **afferent branchial vessels.** The **cardiac aorta**, the forward continuation of the conus arteriosus, runs for about an inch in front of the pericardium, forking to form the anterior two pairs of afferent branchial vessels; the first of these run along the hyoid arch, breaking up into vessels which supply the gill on the posterior face of the hyoid, while the second pair run along the outer border of the first branchial arch, giving off branches to the gills lying on the anterior and posterior surfaces of these. The third, fourth, and fifth afferent vessels run similarly along the second, third, and fourth arches, giving supply to the gills on the anterior and posterior surfaces of these. The last arch, which bears no gill, has no afferent vessel.

The efferent branchial arteries.—A complete arterial loop surrounds each of the four anterior gill-slits, and collects the blood from the gills on their anterior and posterior faces. The posterior slit, which has a gill only

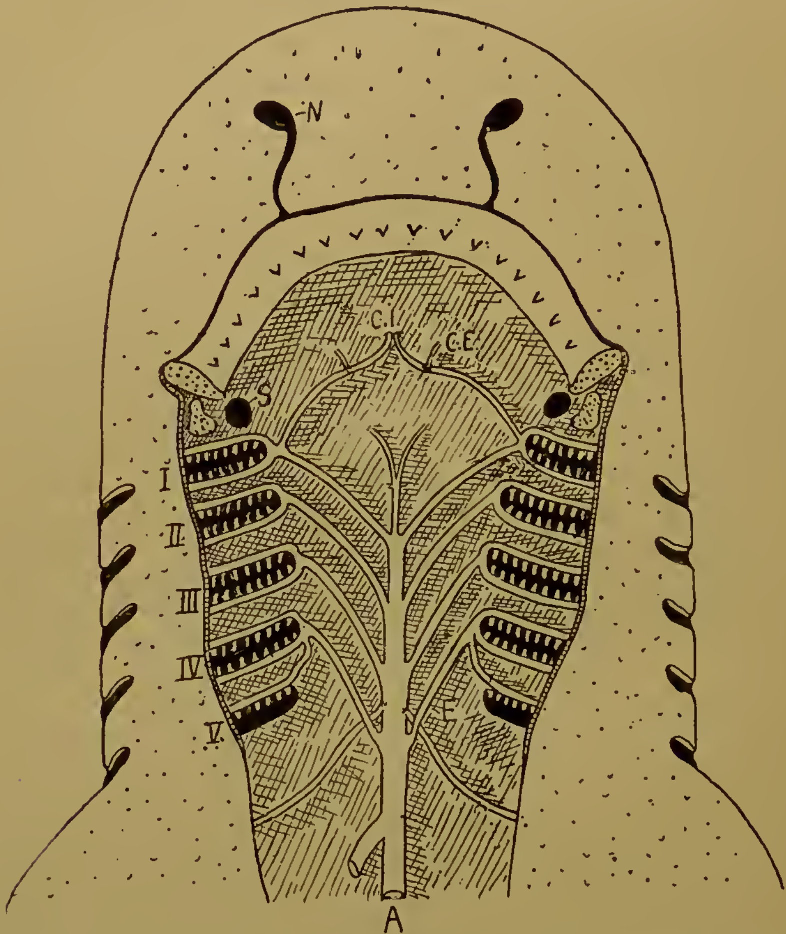

FIG. 52.—Diagram of gill-slits and Arteries. **I.–V.** Gill-cavities: the gill filaments are in white. **A.** Systemic or dorsal aorta. **E.** Posterior efferent branchial vessel. **C.E.** External carotid. **C.I.** Internal carotid artery. **N.** Nostril. **S.** Spiracle.

on its anterior face, returns its blood by a single vessel, which joins the dorsal end of the fourth loop. Cross vessels connect the four anterior loops, and a longitudinal vessel, not represented in the figure, connects their ventral ends. From the dorsal ends of the four anterior loops, four **epibranchial arteries** run inwards and backwards, and unite to form the **dorsal aorta,** which runs back along the whole length of the body under the backbone to the root of the tail, where it enters the hæmal arches.

The **carotid artery** of each side arises from the dorsal end of that part of the first loop which comes from the hyoid gill. It runs forwards and inwards along the ventral surface of the skull to the posterior border of the orbit, where it divides into an external carotid which runs forward to supply the jaws and the snout, and an internal carotid which runs inwards and forwards along a groove in the ventral surface of the skull until it meets its fellow of the other side in the middle line, when the common vessel passes through a foramen into the brain.

The **hyoidean artery** runs from the ventral end of the anterior part of the first efferent loop to supply the spiracle, and also sends a small vessel into the brain through a foramen immediately in front of the interorbital foramen in the orbit.

Branches of the dorsal aorta.

The **subclavian artery** of each side leaves the dorsal aorta between the third and fourth epibranchial vessels, and runs backwards and outwards to the pectoral fins.

The **cœliac artery** is a large median vessel which leaves the ventral side of the aorta shortly behind the last pair of epibranchials, and divides into an artery for the stomach and liver and one for the intestine and the pancreas.

The **mesenteric artery** is a median vessel supplying the intestine and rectum, and arising about two inches behind the cœliac artery.

The **lieno-gastric artery** leaves the aorta immediately behind the mesenteric artery. It supplies the posterior limb of the stomach and the spleen.

The **posterior mesenteric artery** leaves the aorta in front of the anterior end of the rectal gland which it supplies.

The **parietal arteries** are small, paired vessels which leave the aorta at intervals all along its course and supply the body-wall.

The **renal arteries** are small, paired arteries which run from the aorta into the kidneys.

The **iliac arteries** leave the aorta near the posterior end of the abdominal cavity, and one runs to each pelvic fin.

THE RENAL AND REPRODUCTIVE SYSTEMS.

In vertebrates, the excretory and reproductive systems are closely connected, and to understand the complicated relations that exist between them, it is necessary to know something of the way in which the two sets of organs are developed. The reproductive organs, the ovaries in the females, the testes in the males, arise as modified patches of the dorsal wall of the cœlome. In some animals, especially in cases like the common dog-fish, or as in birds, where the eggs, on account of the bulk of food-yolk contained in them, are very large, only one ovary is present in the adult condition; but typically, there is one pair of testes, and one pair of ovaries. The eggs or spermatozoa when ripe would therefore fall into the body-cavity. The primitive kidney consists of a series of nephridia arranged segmentally, so that there is one pair for every segment of the body. The other ends of the nephridial tubes open into a longitudinal duct, called the **segmental duct**, which runs back to open to the exterior by the cloaca. Such a condition is represented in Fig. 53, the nephridia only of one side being represented completely. On each nephridium, between the funnel and the opening into the segmental duct, there is a cup-shaped protuberance in which a coil of blood vessels ramifies, represented in the figure for the sake of simplicity as coming only from the aorta the renal portal system being neglected. Such simple nephridia by the funnels would remove waste matter from the cœlome, and along with this the ripe genital products discharged from the genital glands; while from the blood in the cup-shaped protuberances they would extract waste material. In the actual development of vertebrates such a series of paired nephridia leading into a segmental duct occurs; but this is rapidly followed by that feature of cœlomate development which in Chap. XIII. we called

FIG. 53. — Diagram of primitive Kidney. **A.** Sytemic aorta which sends branches ramifying in the cup of each nephridium. **B.** Nephridial funnels. **S.** Segmental duct. **C.** Cloaca with apertures of ducts.

condensation of segmentation. The series of nephridia is broken up into three groups, and the original

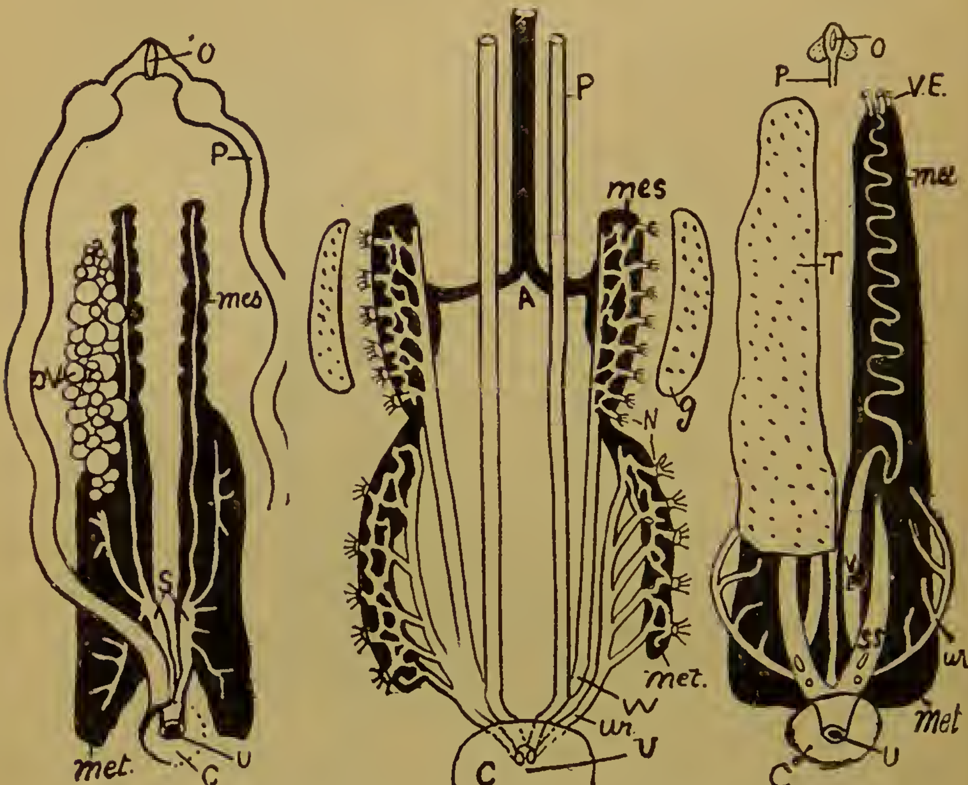

FIG. 54.—Excretory and Genital Organs of Dog-fish. The middle figure is the common type; to the left the female, to the right the male. **A.** Aorta. **Mes.** Mesonephros. **Met.** Metanephros. **P.** Pronephric duct. **W.** Mesonephric duct. **Ur.** Metanephric duct. **G.** Genital organ. **C.** Cloaca. **U.** Urinogenital aperture. In the female, **P**, oviduct with shell gland near the summit. **O.** Common opening of oviducts into cœlome. **OV.** The single ovary. **S.** Urinary sinus into which mesonephric ducts and ureters open. In the male, the testis (**T**) of one side has been removed. **P.** Rudimentary pronephric duct with **O**, opening into cœlome. **V.E.** Vasa efferentia. **V.S.** Vesicula seminalis (mesonephric duct). **SS.** Sperm sac, in the lower end of which are seen the openings of **V.E.** and of **Ur** immediately under the reference letters **SS.**

single segmental duct is replaced or divided, so that a separate duct is formed for each group. The middle drawing in Fig. 54 represents this. The anterior group of nephridia is called the **pronephros** or head kidney, and its duct is called the **pronephric duct.** In the dog-fish the nephridial tubules of the pronephros do not appear, and therefore they are merely dotted in the figure ; but their duct, the pronephric duct, which, as it frequently is the remains of the original duct, is often called the segmental duct, does appear at each side. The second division of nephridia is called the **meso-nephros**, and its duct is the **mesonephric duct**, or from the name of its discoverer, the Wolffian duct. The posterior group is called the **metanephros**, or last kidney, and its duct is the **metanephric duct** or **ureter**, as in most kidneys the metanephros is the only functional kidney of the adult, and the metanephric duct is that by which the urine is actually discharged. In most vertebrates these separate ducts appear successively, but while the metanephros forms the kidney of the adult, only those parts of the pronephros and mesonephros are retained which have become specialised into sexual ducts, because they have retained the primitive auxiliary employment of the nephridial funnels as means by which the ripe generative products escape from the cœlome to the exterior.

The Adult Female.

The **Ovary** is a single large organ lying in the abdominal cavity suspended from the dorsal wall by a delicate mesentery which is easily torn. The ovary is lobulated on account of the large eggs, in various stages of ripeness, which are contained in it.

The **oviducts** are the original pronephric ducts enormously expanded. They are a pair of wide tubes lying on each side of the middle line near the dorsal wall of the cœlome. Their anterior ends meet together in the middle line in front of the liver, and on the ventral side of the point of junction a ventral slit opens, thus placing their cavity in communication with the abdominal cavity. Through this the eggs which have fallen from the ovary into the cœlome find their way, and are impregnated by spermatozoa passed into the oviducts by the males during copulation. Nearly a third of its length from the opening into the body-cavity each oviduct expands to form the oviducal gland which secretes a horny shell formed round the egg after impregnation. The posterior ends of the oviducts unite, and open into the cloaca on the dorsal wall, immediately behind the rectum.

The **mesonephros** is rudimentary and consists of a segmented mass of yellow-brown glandular tissue, arranged in patches on the dorsal wall of the abdominal cavity at each side. The patches are arranged so that they correspond roughly to the vertebræ.

The **metanephros** forms the permanent kidney of the adult female. Each is a compact, laterally-compressed, dark-brown mass lying attached to the dorsal wall of the cœlome, one on either side of the middle line. The original segmentally arranged tubules have greatly multiplied in number. In most cases the nephridial funnels into the cœlome have disappeared, although in some cartilaginous fishes miscroscopic sections through the kidney and the peritoneum show that the apertures of the funnels persist even in the adult. The cup-shaped expansions of the tubules are increased in number, and into them there pass coils of blood-vessels which also ramify over the parts of the tubules within the kidney.

These blood-vessels, which come both from the renal arteries and from the renal-portal system, together with the tubules and a small amount of supporting connective tissue, form the mass of the solid kidney. The cup-shaped expansions with their contained tufts of blood-vessels form the most characteristic feature in sections of the kidney, and are known as **Malpighian corpuscles.**

The mesonephric ducts, in the adult female, form a pair of straight tubes running along the whole length of the kidneys on their ventral surfaces. Their posterior ends are enlarged to form a pair of **urinary sinuses**, which meet together posteriorly and open into the cloaca, on the surface of a small urinary papilla on the posterior margin of the openings of the oviducts.

The metanephric ducts form the **ureters** of the adult. There are four or five at each side, and they open by separate apertures into the dorsal wall of the urinary sinus of each side.

The Adult Male.

The **Testes** are a pair of soft, whitish, elongated bodies lying on the dorsal wall of the abdominal cavity, and united to each other at their posterior ends. At the anterior end of each testis a number of small ducts, the **vasa efferentia**, leave the testes and pass into the anterior ends of the mesonephros of each side. The spermatozoa, when ripe, instead of being discharged directly into the body-cavity, are passed along these ducts to the mesonephros. The pronephros of the adult male, as in the female, is not developed. The pronephric ducts of each side are quite rudimentary ; at the anterior end of the abdominal cavity, in a situation corresponding to the opening into the body-cavity of the female oviducts, there are in the male a couple of small pouch-like sacs in the suspensory ligament of the liver, and behind these a short median strand of tissue represents the anterior parts of the aborted ducts.

The mesonephros of each side forms the front part of the functional kidney of the adult, while the metanephros forms the posterior and larger part of the permanent kidney. A slight constriction usually marks the bounds of the two parts of the kidney, the internal structure of which is similar to that described in the case of the female.

The mesonephric duct of each side is a thick-walled sinuous tube which runs through the whole length of the mesonephros, and into which open the segmentally arranged mesonephric nephridial tubules. Where the mesonephros passes into the metanephros, each mesonephric duct expands into a wide thin-walled tube corresponding in position to the urinary sinus of the female, although it extends further forwards. This is called the **vesicula seminalis**, and it runs back along the ventral side of the metanephros to open into the urino-genital sinus immediately before that opens into the cloaca.

The **sperm-sac** of each side is a thin-walled sac which has no representative in the female. It lies along the outer side of the vesicula seminalis, and ends blindly in front, nearly at the anterior margin of the metanephros. Posteriorly, each dilates to form the **urino-genital sinus.**

The urino-genital sinus of each side receives the openings of the vesicula seminalis and of the ureter, and then the two unite and open into the cloaca by a small pore at the tip of the **urino-genital papilla**, which is situated immediately behind the rectum.

There are five **metanephric ducts** at each side. The anterior four unite to form the **ureter**, which is joined by the fifth and then runs along the dorsal surface of the vesicula seminalis to open into the urino-genital sinus.

Thus in the male the mesonephric duct functions both as the ureter of the mesonephros and as a vas deferens by which the genital products, brought to the mesonephros by the vasa efferentia, leave that to reach the exterior. The urino-genital papilla on which the urino-genital sinus opens serves as a common aperture for the escape of excretory and sexual products. In copulation the genital products are directed into the body of the female by grooves running along the dorsal surface of the claspers.

THE NERVOUS SYSTEM.

The nervous system of vertebrates is tubular and hollow, and lies along the dorsal surface with an anterior expansion in the head forming the brain. In Fig. 72, which is a longitudinal vertical section through a young vertebrate embryo, a primitive condition of the nervous system is shown. It consists of a hollow tube, open to the blastopore behind, and in front is expanded into three bulbs, lying one behind the other, named the three primary vesicles of the brain. In the course of the development, the solid parts of the brain and spinal cord are formed by thickenings in the walls of the primitive tube and vesicles, and the cavity remains as a small **central canal** in the spinal cord leading into a series of **ventricles** in the brain. From this central portion the peripheral portion, consisting of nerves growing out in pairs, runs to the tissues and organs.

The anterior part of **the first primary vesicle of the brain** grows out to form a large thick-walled mass partly divided by a longitudinal constriction into two lateral halves. This is called the **prosencephalon**, or forebrain ; its lateral halves form the cerebral hemispheres of higher animals, and contain the lateral ventricles. From the side near the front grow out the olfactory lobes. The posterior half of the first vesicle forms the **thalamencephalon.** From each side of it grows out a bulb which nearly meets the outer surface of the body. As shown in Fig. 73, the anterior wall of each of these lateral bulbs tucks in backwards so that they form cups, carried upon short stalks. These cups form the nervous portion of the eyes ; the stalk forms the optic nerve, and a thickening of the outer skin opposite the mouth of the cup forms the lens of the eye. The dorsal wall of the thalamencephalon gives rise to a stalked bulb, which becomes cup-shaped exactly like the lateral eyes. In the dog-fish, and in most other living vertebrates, this dorsal eye degenerates, and becomes a stalked bulb on the surface of the brain, known as the **pineal body.** But in some living lizards this bulb actually developes into a small structure with the anatomical characters of an eye. This is visible on the surface of the head in the middle of the parietal region, and is called the parietal eye. It is not functional even in those animals in which at the present day it is most highly developed, but there is good reason to suppose that in the extinct ancestors of living vertebrates it served as a third eye. The parietal eye, or pineal body as it now exists, is a notable instance of a rudimentary organ, that is to say, it is a relic of an organ no longer functional, but which still lingers on in development. Another bulb grows out on the ventral side of the thalamencephalon and becomes what is called the

infundibulum, on the under surface of which is the **pituitary body**, another organ probably rudimentary, of which the history and function are extremely doubtful.

The walls of **the second primitive vesicle** thicken and form the **optic lobes**. The cavity remains as the **iter a tertio ad quartum ventriculum.**

The third primitive vesicle constricts into two portions. The dorsal part of the anterior portion forms the **cerebellum** ; the posterior portion, the roof of which remains very thin, forms the **medulla oblongata**, and its cavity becomes the fourth ventricle.

The tube forms the **spinal cord**, the walls becoming very thick and the cavity being reduced to a small central canal.

Dissection of the brain in the dog-fish is important, because the primitive condition is not much departed from, whereas in higher vertebrates, such as man, complicated bending and folding of the originally straight tube occurs.

Dissection of the nervous system is most conveniently performed upon specimens that have been hardened in spirit. When the viscera have been examined the animal should be put in methylated spirit for a few days, the dorsal wall of the skull having been removed. Then it must be placed on the dissecting board with its dorsal side upwards, and pinned down. The skin must be removed from the dorsal surface of the head, and then, if this has not been done before, the cartilaginous roof of the skull must be sliced away until the brain has been exposed. The auditory capsule and the orbit of one side should be left intact. The capsule of the other side must be sliced through while exposing the brain, and the eyelids of the same side dissected away to expose the orbit. As the orbital sinus is opened in this process, the blood clots must be washed away. Then the surface of the brain must be examined: next the eye of one side examined: next the cranial nerves must be dissected; and lastly the brain and a part of the spinal cord must be removed and examined more fully. In this description the order to be observed in the laboratory will not be followed exactly.

THE DORSAL SURFACE OF THE BRAIN.

The **prosencephalon** forms the largest and most anterior part. It is a smooth, somewhat rounded mass lying between the olfactory capsules and the orbits. The separation into lateral hemispheres is marked only by a slight, median anterior groove.

The **olfactory lobes** arise by stalks from the middle of the sides of the prosencephalon. They are triangular in shape and are closely pressed against the sides of the prosencephalon. In the dog-fish, as in many other predatory fishes which make large use of the sense of smell in hunting, these olfactory lobes are unusually large.

The **thalamencephalon** is the narrower portion of the brain immediately behind the anterior part. Its roof is very thin, and the third ventricle can be seen through it.

The **pineal body** extends forwards from the hinder part of the roof, and terminates in a slightly expanded bulb lying on the surface of the forebrain. The optic nerves, which represent the stalks of the optic vesicles, may be seen running into the eyeball from under the lower part of the sides of the thalamencephalon.

The **optic lobes** are a pair of rounded expansions which in front partly overlap the thalamencephalon, and behind are partly overlapped by the cerebellum. The fourth pair of nerves arise from near the middle dorsal line between the optic lobes and the cerebellum.

The **cerebellum** is an elongated, oval body, which stretches far forwards over the optic lobes and backwards

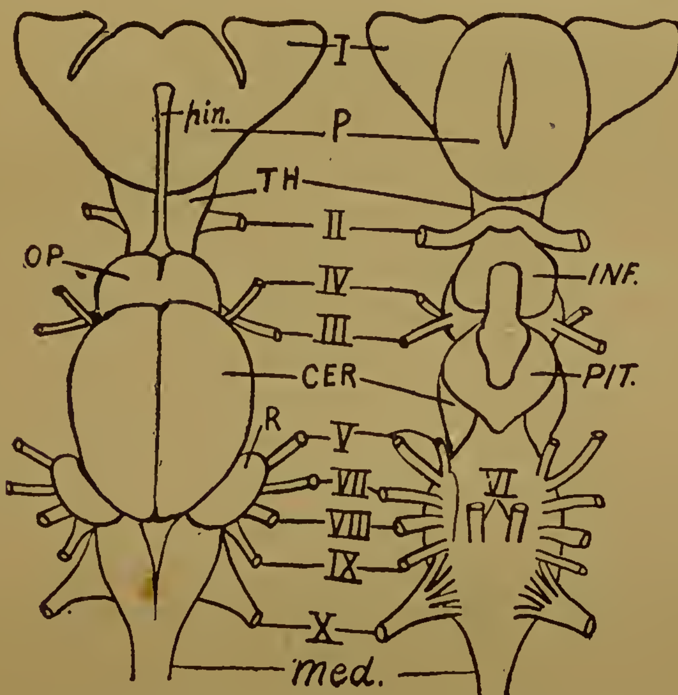

FIG. 55.—Brain of Dog-fish. To the right, ventral; to left, dorsal aspect. I. Olfactory lobes. P. Prosencephalon. Pin. Pineal. TH. Thalamencephalon. OP. Optic lobes. INF. Infundibulum. PIT. Pituitary. CER. Cerebellum. R. Restiform bodies. Med. Medulla oblongata. II. Optic nerves. III. Third nerve. IV. Fourth nerve. V. Fifth nerve. VI. Sixth nerve. VII. Seventh nerve. VIII. Auditory nerve. IX. Glossopharyngeal. X. Vagus.

over the medulla oblongata. Its surface is slightly folded transversely, giving it a lamellar appearance.

The **medulla oblongata** forms the posterior part of the brain. It narrows as it passes back into the spinal cord. Its roof is very thin, and in dissection is frequently torn away, exposing the cavity, the fourth ventricle. The roots of the fifth, seventh, and eighth nerves may be seen coming from its sides in the anterior region. The slender ninth nerve and the several roots of the tenth nerve may be seen arising from the sides of the medulla in the posterior half, while above these there is a large rounded expansion at each side, the **restiform** body.

THE VENTRAL SURFACE OF THE BRAIN.

The examination of this must be deferred until the cranial nerves have been examined.

The prosencephalon and the olfactory lobes appear much as when seen from the dorsal surface, but they pass more directly into the thalamencephalon.

The thalamencephalon, on the greater part of its ventral surface in front, has a curved band, from the ends of which the optic nerves arise. This band is the **optic chiasma**, and is formed by a complicated crossing of the fibres coming from the right and left sides, so that the greater part of the nerve to the right eye comes from the left side of the brain and *vice versa*.

The **infundibulum** is a pair of hollow, oval protuberances (*lobi inferiores*), on the ventral surface of the thalamencephalon, immediately behind the optic chiasma. Attached to the posterior end of the infundibulum is the **pituitary body**, a thin-walled bi-lobed, hollow sac. A tubular body, of unknown function, is attached along the middle line of the ventral surface of the pituitary and runs forward to the infundibulum.

The roots of the third nerve issue in the middle line from the ventral surface of the thalamencephalon between the infundibulum and the pituitary.

The medulla oblongata is narrow in front and behind. From the ventral surface near the middle line arise the small roots of the sixth nerve, and from the sides arise successively the fifth, seventh, eighth, ninth, and tenth nerves.

THE CAVITIES OF THE BRAIN.

The original hollows of the vesicles are broken up into a series of ventricles opening into each other from behind forwards. The cavity of the medulla is the **fourth ventricle**: the restiform bodies and the cerebellum are hollow outgrowths of the dorsal wall. The cavity of the mesencephalon which communicates behind with the fourth ventricle, is narrow, but the optic lobes are hollow protuberances of its dorsal wall. This leads into the cavity of the thalamencephalon, the **third ventricle**, which communicates above with the hollow pineal body, below with the hollow infundibulum. This leads into the cavity of the prosencephalon, which is divided by a median partition into lateral ventricles which communicate with the hollow olfactory lobes.

THE CRANIAL NERVES.

These are of the greatest importance, because they correspond in relative position and partly in function with those in all the higher vertebrates. If we allow for two important changes, the nerves from the brain in the dog-fish and in man are identical. The first difference is this ; in man, and in higher vertebrates, the process of cephalisation, or condensation of anterior segments to form a head, has proceeded further, and there are two additional pairs of nerves arising from the posterior part of the brain corresponding with the anterior nerves of the spinal cord in the dog-fish. Next, in man the gill-slits and gill-bars, which form so important a part of the anterior region of the dog-fish, are an evanescent occurrence in very early embryonic development, and the distribution, although not the origin of the cranial nerves, is therefore different in many respects. The cranial nerves of the dog-fish should be dissected after the dorsal surface of the brain has been examined. Those of one side only are described.

I. **The olfactory nerve** arises as a bundle of fibres from the anterior end of the olfactory lobe and passes through the membrane separating the brain from the cavity of the nose, by a series of holes. The fibres are distributed to the sensory membrane of the nose.

II. **The optic nerve** runs from the end of the chiasma, through the optic foramen into the orbit, and then straight across to the eyeball.

III. **The third nerve,** or **motor oculi,** is a slender nerve which arises from the ventral surface of the thalamencephalon, enters the orbit by a special aperture and is distributed to the muscles of the eye, except the external rectus and superior oblique.

IV. **The fourth nerve,** or **patheticus,** is a slender nerve which arises from the dorsal surface of the mid-brain, enters the orbit by a small aperture above that of the optic nerve and passes to the superior oblique muscle of the eyeball.

V. **The fifth nerve,** or **trigeminal,** is the most anterior of those leaving the side of the medulla at its broadest part. Before leaving the cavity of the skull it gives off **the ophthalmic** branch, which enters the orbit by a special foramen and runs forward in a groove in the wall of the orbit to an aperture in the anterior, superior angle by which it passes to the skin of the snout, through a canal between the olfactory capsule and the cranium. The main stem of the fifth enters the orbit, sharing a foramen in the posterior part of the orbit with a group of nerves. It then divides into a **maxillary** branch to the snout, and a **mandibular** branch to the lower jaw.

VI. **The sixth nerve**, which is very slender, arises from the ventral surface of the medulla, enters the orbit with the main branch of the fifth, and passes into the external rectus muscle of the eyeball.

VII. **The seventh**, or **facial nerve**, leaves the side of the medulla next behind the fifth. Its first great branch, the **ophthalmic branch**, arises by a separate root higher up the side of the medulla than the main root. It enters the orbit by a separate foramen above that for the ophthalmic branch of the fifth, runs along the orbit in a groove also above that of the fifth, leaves the orbit along with that branch of the fifth and has a similar distribution. The main stem of the seventh enters the orbit with the main stem of the fifth, and divides into a **palatine nerve**, which runs to the roof of the mouth, and a **spiracular nerve**, which runs to the top of the spiracle and forks there, the anterior limb of the fork splitting up into several short branches, while the posterior supplies the posterior edge of the spiracle.

VIII. **The eighth nerve**, or **auditory nerve**, leaves the side of the medulla behind the seventh, and runs straight into the auditory capsule to be distributed to the sensory parts of the ear.

IX. **The ninth**, or **glosso-pharyngeal nerve**, arises from the side of the medulla next behind the auditory nerve. It leaves the skull by a foramen at the end of the post-orbital groove, and runs out to the summit of the first branchial cleft, over which it forks, one branch running along the anterior, the other along the posterior border of the cleft.

X. **The pneumogastric**, or **vagus nerve**, arises from the side of the medulla by several roots. Within the skull it runs backwards a short distance, and emerges at the hind end between the cranium and the auditory capsule. It then runs backwards along the inner wall of the anterior cardinal sinus. From near its root it gives off a nerve which runs along the side of the body to the posterior end, supplying the sense-organs of the lateral line. Next it gives off four branchial nerves, which fork over the four posterior gill-slits. The main stem gives off branches to the heart and stomach.

The spinal nerves arise in pairs from the sides of the spinal cord. Each has a **dorsal** or **sensory** root provided with a ganglion and leaving the neural canal by a notch in the posterior border of the intervertebral neural plate, and a **ventral** or **motor** root which consists of several separate bundles rapidly uniting to leave the neural canal by the notch in the posterior border of the vertebral neural plate; it then joins the sensory root.

Connected with the motor roots of the spinal nerves are a series of wandering ganglia which regulate the viscera and are known as the sympathetic system.

Even in the dog-fish the process of cephalisation has obscured the primitive simplicity of the cranial nerves to a considerable extent. There is reason to believe that the cranial nerves represent modifications of simple segmental nerves, built on a type resembling that of the spinal nerves, but specially modified in connection with the gill-slits, of which, in the typical vertebrate, there were originally a larger number than five. The typical cranial nerve would consist of a dorsal sensory root with a sensory ganglion and a ventral motor root. But the suppression and alteration of some of the gill-slits, and the formation of mouth and jaws during the process of cephalisation, has altered the primitive simplicity.

The olfactory nerve represents the dorsal sensory part of a segmental nerve of which the ventral motor part has been lost.

The optic nerves are really not cranial nerves at all, but are special outgrowths of the brain.

The third nerve has its sensory part degenerate and formed only by a few fibres to the integument on the side of the orbit. The motor root gives rise to the nerves for the eyeball muscles.

The fourth nerve has a few fibres to the conjunctiva, as degenerate sensory part. The motor part is the nerve to the superior oblique muscle.

The fifth and sixth nerves together represent probably a single primitive nerve which has been considerably extended. The first and second branches are chiefly sensory, and represent the sensory part which has been extended to supply missing sensory portions of the third and fourth nerves. The sixth nerve and the third branch of the fifth represent the motor part of the segmental nerve. It is possible, however, that this group represents two segmental nerves.

The seventh also is a complete nerve of which the ophthalmic branch forms the sensory portion, as the fibres in the dog fish are said to contain both sensory and motor parts, although in higher animals the motor part alone is retained. The branch which forks over the spiracle represents the motor part.

The eighth nerve is the sensory part of a nerve of which the motor branch has been lost.

The ninth nerve has the sensory portion degenerate, while the forks over the anterior gill-cleft represent the motor part.

The tenth nerve represents probably several segmental nerves fused together. The nerve to the lateral line represents the sensory part, while the forks over the gill-clefts and the visceral nerves represent the motor part.

THE SENSE-ORGANS.

Sense-organs of the mucous canals. These canals, which ramify on the head and along the lateral line, are seen from the exterior as a series of minute apertures from which mucus may be pressed out. Lying in the canals are a set of sense-organs connected with the fifth nerve on the head, and with the vagus along the lateral line. Each sense-organ is a little bulb of sense-cells provided with sense-hairs, the bulbs sometimes being covered by a cuticular dome. From the base of the group of cells a nerve fibre runs to the nerve. They should be examined by cutting and staining transverse sections of portions of the lateral line.

The nasal organs. On the ventral surface, shallow, curved grooves lead from the angles of the mouth to the apertures of the nasal capsules. The aperture of the nasal organ itself leads into a large sac, which should be cut open and washed out. The sac is lined by mucous membrane thrown into folds and containing groups of sensory cells which are supplied by branches of the olfactory nerve. The nasal organs in elasmobranchs, unlike those of higher animals, are purely sensory, and are unconnected with respiration.

The eyes. The eyeball is a hollow sac with a cartilaginous outer coat, the **sclerotic**, to which six muscles run from the walls of the orbit. Four **recti muscles** run from the posterior wall of the orbit and diverge as they approach it. The **rectus superior** is inserted on the dorsal surface, the **rectus inferior** on the ventral surface, the **rectus externus** on the outer and posterior surface, the **rectus internus** on the inner, more anterior surface of the eyeball.

The oblique muscles run backwards from the anterior wall of the orbit, the **obliquus superior** being inserted on the dorsal, the **obliquus inferior** on the ventral surface of the eyeball, the insertions being immediately in front of the superior and inferior recti.

The eyeball should be removed, by cutting through the optic nerve and the attachments of the muscles, then opened by cutting it into an inner and outer half with a razor. The halves must be examined under water. The **sclerotic coat** is a thin cartilaginous layer which usually articulates by a knob, near the entrance of the optic nerve, with a corresponding depression in the posterior wall of the orbit. The anterior part of the sclerotic is transparent, and forms the **cornea**, through which light reaches the interior of the ball. It is nearly flat exteriorly, this being a characteristic feature of aquatic animals. The **choroid** is an opaque, black, deeply pigmented layer lying closely applied to the inner side of the sclerotic. It contains a plexus of blood-vessels. The layer turned towards the light is covered by a dense glistening surface, the **tapetum.** The choroid is incomplete in front leaving a circular area opposite the cornea. This forms the pupil of the eye, and is surrounded by a layer called the **argentea,** filled with clear, glancing crystalline bodies. The **retina** forms the innermost layer of the eyeball. It is a soft, thick layer continuous with the optic nerve behind, which passes through the two outer coats of the eyeball. The retina is the part of the eye sensitive to light, and in development arises from that outgrowth of the thalamencephalon known as the optic vesicle.

The **lens** is a globular, transparent body occupying the front part of the eyeball. In the dog-fish, as in other aquatic animals, it is more spherical than in terrestrial animals. The remaining cavity of the eyeball is filled by a small amount of **vitreous humour,** which, like the lens, is refractive, and aids the lens in focussing the light upon the retina.

The Ear.

A primitive ear is an organ for registering vibrations rather than for what we know as sound. In its simplest form, as found in some invertebrate animals, it consists of a pouch of the skin opening to the exterior by a narrow aperture, and provided with cells communicating with a sensory nerve by their inner ends, while on their outer surfaces sensory hairs project into the cavity. The water in which the animals live has access to the cavity from the outside, and in the cavity lie several small particles of stone, which either have come there accidentally or have been formed as limy secretions by the cells of the cavity. Vibrations in the water cause these stones or otoliths in the cavity to stimulate the sensory hairs, and the stimuli are transmitted by the nerves to the nerve centres. In vertebrates the ears first appear as little cavities of this kind open to the exterior, and lined by sensory cells which communicate with nerves. But in subsequent development the auditory pouches sink deep into the cartilage of the skull, and the connection with the exterior in most cases disappears.

The ear of the dog-fish consists of a membranous sac, the **vestibule**, from which arise three **semicircular canals**, contained in hollows of the cartilaginous auditory capsule. It must be examined by gradually paring away the cartilage of the capsule from above downwards. When the skin has been removed from the surface of the capsule there is at once visible a prominent anterior ridge which lodges the anterior canal, and a posterior ridge for the posterior canal. Between these two is a small aperture which leads into a tube, the **aqueductus vestibuli**, which opens into the vestibule. It is not known to have any function in the adult animal, but is the remains of the original invagination of the outer skin which was the starting-point of the ear.

The vestibule is a membranous sac lying loosely in the cartilaginous capsule, and partly divided into a lower portion or **sacculus**, and an upper portion or **utriculus** which receives the ends of the semi-circular canals. It contains calcareous concretions.

Each **semicircular canal** opens into the utriculus by an expansion, the **ampulla**, then curves through the cartilage, and at its other end again opens into the utriculus. The ampulla of the anterior vertical canal is close to the orbit in the front end of the capsule ; its hinder end opens into a dorsal protuberance about the middle of the utriculus. Into the same protuberance opens the anterior end of the posterior vertical canal, which is much longer, and bends down behind the utriculus until, nearly completing a circle, it enters that by an ampulla at the posterior end. The ampulla of the horizontal canal opens near that of the anterior vertical canal. The horizontal canal then curves outwards in a lateral expansion of the capsule, and, completing the half circle, enters the utricle near the ampulla of the posterior vertical canal. The auditory nerve, which enters the capsule on the side turned to the skull, breaks up into branches which pass to the ampullæ and to the vestibule.

CHAPTER XVII

THE FROG

THE frogs and toads belong to a group of vertebrates known as **amphibia**, and specially characterised by the fact that their respiration is effected both by gills and by lungs. In them all the gills appear first. In some of the lower amphibia the gills persist even after the lungs have come into use. In most cases the gills are confined to a larval, fully aquatic stage, the tadpole stage in the frog, while the lungs are the organs of respiration in the adult condition. In the larval condition, and in the adults of some forms like newts, there is a fish-like lateral line with sensory organs, and unpaired dorsal, ventral, and caudal fins. In the frogs and toads these disappear in the adult, and locomotion is effected by jointed fore and hind limbs, which, unlike the paired fins of fishes, are broken up into arms, wrists, and hands, or legs, ankles and feet, and, like the paired fins, are attached to the pectoral and pelvic girdles.

There are probably several species of frogs native to this country. Of these the most common is the grass frog, *Rana temporaria*, which may be distinguished at once by a large black patch in the temporal region between the eye and the shoulder. *Rana esculenta*, the green water frog, is usually lighter in colour, and is a larger animal. It is not so abundant in this country, or from its more aquatic habits is less often obtained. The colour of the skin in both species is due to the presence of branching cells loaded with pigment. Under the influence of light, and apparently of differences in the colour of the environment, these pigment corpuscles change in shape and distribution, so that the resulting colours more or less correspond to the colours of the environment. These changes are to a certain extent under the influence of the central nervous system, and frogs which have been blinded are stated not to undergo them.

EXTERNAL CHARACTERS.

The body is divided into a head, trunk, and limbs. The skin is moist and smooth and devoid of hairs or scales. The mucus, secreted by the skin, is harmless in frogs. In the nearly allied toads it is slightly poisonous and irritant. In both cases it serves as a protection against the attacks of other animals, especially of such marauding insects as ants in the case of the land forms, and against parasitic ticks and growths of hydroids in the aquatic stages. The head is flat and triangular; at each side it bears the large eyes protected by an upper, fixed eyelid and a lower, transparent, movable eyelid. Behind the eye on each side, in *Rana temporaria* in the middle of the black temporal patch, is a flat circular membrane, stretched tightly over a marginal ring. This is the tympanic membrane.

Apertures. The **mouth** is a wide horizontal slit at the anterior end. The **external nostrils** are a pair of small apertures on the dorsal surface of the head near the anterior end, which during life are constantly being opened and closed. The **cloacal aperture** is a small hole at the posterior end of the trunk, between the legs, but on the dorsal rather than the ventral surface of the body.

Buccal cavity. This must be opened widely and washed out. If the frog has just been killed some of the cells should be scraped off the posterior part of the roof and examined in water under the microscope, that their ciliary motion may be seen.

The **maxillary teeth** are a single row of small teeth lining the edge of the upper jaw; the lower jaw is devoid of teeth. The **vomerine teeth**, in *Rana esculenta*, are arranged in two small clusters on the roof of the mouth between the internal nasal openings. In *Rana temporaria* they are smaller, and form oblique patches diverging in front, but in the same region.

The **posterior nares** are two small apertures in the roof of the mouth communicating with the exterior through the external nostrils.

The **eustachian** tubes (Fig. 59. *e*) are recesses in the sides of the posterior part of the roof of the mouth. They lead into the cavity under the tympanic membrane.

The eyeballs may be seen projecting into the cavity of the mouth at each side.

The **tongue** is a thin fleshy protuberance attached to the front part of the floor of the mouth, and forked at its extremity. In the condition of rest it lies folded back on the floor of the mouth, but may be shot out forwards.

The **glottis**, by which air passes through the **larynx** into the **lungs**, is a longitudinal slit in the floor of the posterior part of the mouth, and is supported laterally by the **arytenoid cartilages.**

SKELETON.

The skeleton of the frog should be studied before the dissection of the viscera is undertaken. The **skeleton of the frog** presents a great advance on that of the dog-fish, as there are in addition to pure cartilage and to cartilage hardened by deposits of calcareous matter a number of **true bones**; especially in the case of the skull many of these bones may be picked off as if they were bony plates plastered upon a cartilaginous framework. The skeleton should be studied in a specimen carefully cleaned and kept in spirit, as well as by the dissection of a fresh specimen.

The **vertebral column.** The vertebræ are fully ossified, and are attached to each other by special **articular processes,** while the adjoining faces of the centra are covered by cartilaginous discs. In most of them these discs are hollowed out in front, and with these hollows the bulging posterior ends of the vertebræ next in front articulate. Such centra, hollow in front, are called **procœlous.** Owing to the complete separation of the vertebræ the notochord is not continuous as in the dog-fish, but within each centrum remains of it persist, surrounded by a delicate sheath.

There are nine separate vertebræ and a long bone behind, the **urostyle,** which is articulated by two facets to the ninth vertebra, and which represents a number of posterior vertebræ fused together. Thus the vertebral column of the frog exhibits not only segmentation, but the partial fusion and telescoping of some of the segments.

Each of the vertebræ bears a **dorsal arch**, enclosing the spinal cord and carrying a short backwardly directed spine above, and at each side a horizontal articular process. Each of the articular processes has two articular facets; the anterior facets look downwards, the posterior facets upwards, and the downward facets overlap the upward facets of the vertebra next behind. Each vertebra, except the first, or **atlas**, has at each side a stout transverse process, with which is indistinguishably fused a short rudimentary **rib**. The transverse processes of the last free vertebra are very stout, and at their outer ends articulate with the tips of the iliac bones. It is called the **sacral vertebra**.

The **urostyle** has a dorsal ridge for the first half of its length, and the neural canal extends into it for about the same distance.

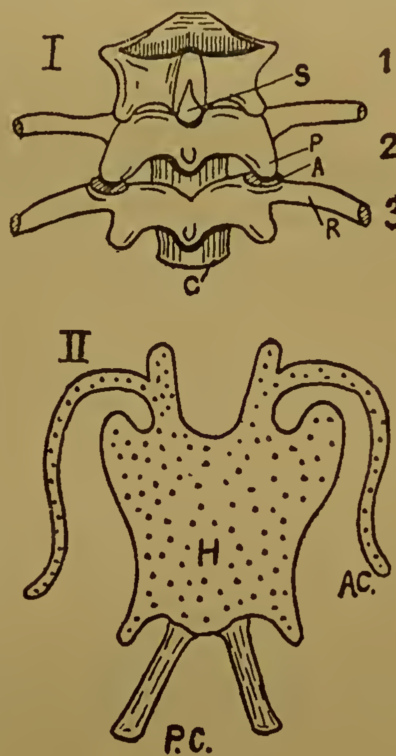

FIG. 56.—I. Three Anterior Vertebræ of Frog from dorsal aspect. **1.** Atlas; **2.** and **3**, second and third vertebræ. **S.** Spine. **R.** Ribs. **P.** Posterior downturned face of articular process. **A.** Anterior upturned face.

II. Hyoid of Frog. **H.** Body of Hyoid. **AC.** Anterior cornu. **P.C.** Posterior cornu.

The skull of the frog is at first sight very different from that of the dog-fish, but careful study of the tadpole, the fish-like stage of the frog, has shown that in the course of development the skull passes through a **cartilaginous stage** in which it is a shallow box imperfect above, with nasal capsules wedged into it in front, and with ear-capsules wedged into it behind, scooped out at the sides to form orbits for the eyes, and with a series of gill-arches below. The changes from this dog-fish like condition to the adult condition are comparatively simple. The jaws, which in the dog-fish were entirely under the skull, and did not reach the anterior end, are expanded into great half-hoops, which project beyond the anterior end of the cranium in front and behind, and are so much wider than the skull that the suspensorium is formed by struts thrown outwards from the region of the auditory capsule to serve as articular supports. The upper jaw in front, instead of being merely slung to the base of the skull by ethmopalatine ligaments, is firmly united with the base of the skull. So far, the skull may be compared in shape to a cross-bow. The cartilaginous cranium and the vertebral column behind it represent the line of the stock of the bow. The upper and lower jaws represent the actual bow when bent to a half-hoop, and the struts, running out from the hind end of the auditory capsules to the angles of the jaw, represent the string of the bow.

The branchial arches, except the first which forms the jaws, are united together to form a flat plate, the **hyoid** plate, which lies under and between the lower jaws.

Next, definite cartilage bones are formed in various regions of the cartilaginous skull, and lastly various membrane bones, really formed by the ossification into flat plates of the bony bases of scale-teeth, like those of the dog-fish, are plastered over the underlying structures in various regions.

The description to follow should be compared carefully with a prepared skull; then the skull of a freshly-killed frog should be skinned, plunged for a few minutes in nearly boiling water, and carefully cleaned by brushing and scraping. The membrane bones should first be examined and removed, and then the general structure of the cartilage and the cartilage bones studied.

Membrane Bones of the Skull.—The **fronto-parietals** are a pair of elongate flat plates, united by a suture along the middle line, and forming the roof of the greater part of the brain case.

The **nasals** are a pair of flat triangular bones lying behind the nostrils, on the front part of the roof of the skull.

The **squamosals** are a pair of T-shaped bones behind and to the inside of the tympanic membrane. The long arm of the T projects outwards and backwards, and forms the dorsal covering of the suspensorium. One end of the cross-limb of the T reaches the posterior edge of the top of the skull, the other projects outwards and forwards.

The **premaxillary bones** are two bones united in the middle line, and together forming the anterior part of the upper jaw. Each consists of a lower plate bearing a single row of teeth, and an ascending process which forms a movable articulation with the nasal cartilage.

The **maxillæ** are two elongated curved bones, each of which unites in front with one of the premaxillæ, and so continues the outline of the upper jaw. Behind, the maxillæ unite with the **quadrato-jugals**, which overlap them on the outer side. The maxillæ bear a single row of teeth.

The **quadrato-jugals** are a pair of slender bones which complete the outline of the upper jaw behind; their broader posterior ends form part of the articular surface for the lower jaw. They have no teeth.

The **parasphenoid** is a dagger-shaped bone which lies on the under surface of the skull, nearly opposite the

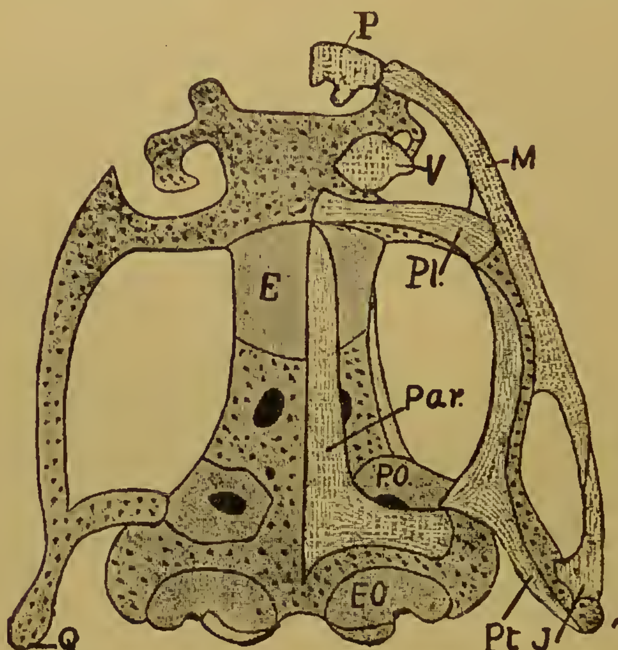

FIG. 57.—Skull of Frog (cartilage dotted, membrane bones light, cartilage bones darker). Ventral view: membrane bones of the right side stripped off. **P.** Premaxilla. **M.** Maxilla. **J.** Quadrato-Jugal. **Pt.** Pterygoid with cartilaginous pterygoid below it. **Pl.** Palatine. **V.** Vomer. **P.O.** Pro-otic. **E.O.** Exoccipital. **Q.** Quadrate (suspensorium). **E.** Sphenethmoid. (Partly after Ecker.)

fronto-parietals. The handle of the dagger is very short, and nearly reaches the lower edge of the foramen magnum. The guard or cross-piece underlaps the auditory capsule of each side. The blade points forwards and ends in the middle line, on a level with the front of the orbits.

The **vomers** are a pair of small bones on the under surface of the front part of the skull, just behind the internal nostrils, and so nearly opposite the nasals. Each bears a small plate which carries teeth.

The **palatines** are a pair of small narrow bones on the under surface running at right angles to the long axis of the skull from behind the vomers to the maxillæ.

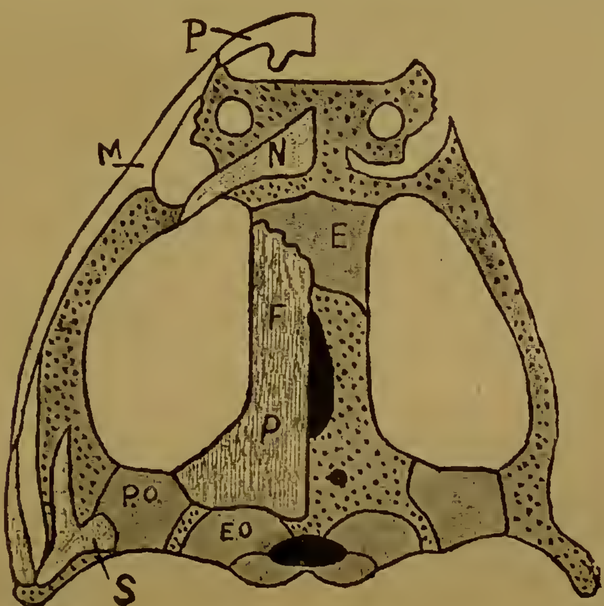

FIG. 58.—Skull of Frog (cartilage dotted, membrane bones, shaded light, cartilage bones darker). Dorsal view: membrane bones of right side stripped off. **P.** Premaxilla. **M.** Maxilla. **S.** Squamosal. **F.P.** Fronto-parietal. **N.** Nasal. **E.** Sphenethmoid. **E.O.** Ex-occipital. **P.O.** Pro-otic. (Partly after Ecker.)

The **pterygoids** are a pair of curved, three-armed bones partly, but not wholly, of membranous origin. The shortest arm is internal, and ends beside the front edge of the guard of the parasphenoid. The longest arm runs forwards and meets the outer tip of the palatine, and for some distance behind this is in contact with the inner edge of the maxilla, but leaves the maxilla before that meets the quadrato-jugal. The third or outer arm runs from the junction of the inner and anterior arms along the ventral surface of the suspensorium, and its tip forms a small part of the articular surface for the lower jaw.

The **articular** bone at each side forms the hinder and lower part of the lower jaw.

The **dentary** of each side forms the part of the lower jaw in front of the articular, but the two dentaries do not meet in front. Notwithstanding their name, the dentaries do not carry teeth in the frog.

When these membrane bones have been stripped off, the true cartilaginous skull becomes visible. It is seen to be an unsegmented cartilaginous tube with the cartilaginous sense capsules stuck in at the sides. It is imperfect above, there being under the fronto-parietals one large anterior fontanelle and two small posterior fontanelles. In three regions the cartilage of the skull is replaced by cartilage bones.

Cartilage and Cartilage Bones of the Skull.—The **ex-occipitals** are two irregular bony masses at the posterior end of the skull, almost completely surrounding the foramen magnum. On their posterior faces they bear the **occipital condyles**, two oval convex processes which articulate with the **atlas** or first vertebra.

The **pro-otics** are a pair of irregular bones, forming part of the anterior walls and the roof and floor of the auditory capsules.

The **sphenethmoid** or girdle bone is a bony tube forming the anterior end of the cranium ; it extends forwards into the olfactory region. It is provided with a vertical bony partition which separates the cavities for the right and left olfactory lobes of the brain.

The **upper jaw** consists entirely of a cartilaginous arch overlaid by the membrane bones which have been described.

The lower jaw also is a cartilaginous arch overlaid by membrane bones. The upper part of the arch at each side is a rod of cartilage, the **quadrate**, which forms the suspensorium by which the jaw is suspended to the skull. Its upper end is fused with the auditory capsule, and runs downwards and backwards to the angle of the mouth, where the **quadrato-jugal** meets it. The squamosal and pterygoid bones cover it, and the cartilaginous part of the pterygoid meets it. The lower part of the arch at each side forms what is called **Meckel's cartilage.** The inner and lower surface of this is ossefied as the **angulosplenial** bone, while another small bone, the **mento-meckelian**, lies at the point where the lower jaws of each side meet in front.

In the frog the gill-arches are greatly modified, owing to the disappearance of the gill-slits in the adult condition.

The **first or mandibular** arch forms the quadrate and the upper and lower jaws

The tip of the second or **hyoid** arch at each side is separated off to form the columella or ear-bone. This is a rod partly bony, partly cartilaginous, the inner end of which is inserted into the **fenestra ovalis**, a cavity in the outer wall of the auditory capsule. The other end of the columella runs out to be attached to the inner side of the tympanic membrane.

The rest of the hyoid arch and the remains of the branchial arches are fused into a median ventral plate with anterior and posterior horns, which lies in the floor of the mouth between the lower jaws. The **anterior**

cornua are a pair of slender rods of cartilage attached by their lower ends to the median plate, and by their upper ends to the auditory capsule just below the attachment of the columella. The **posterior cornua** are a pair of stout bony processes diverging backwards from the hinder border of the body of the hyoid.

Skeleton of the Girdles. The **pectoral girdle** consists of

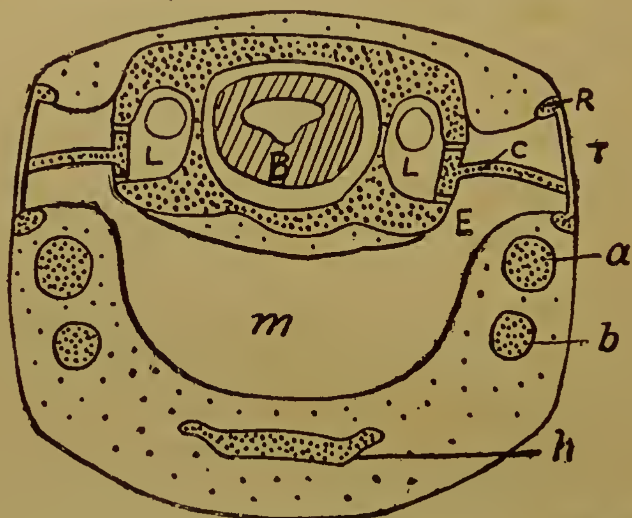

FIG. 59.—Diagrammatic Section through Head. Skeleton closely dotted. **B.** Brain. **L.** Internal ear with membranous labyrinth (very diagrammatic). **C.** Columella. **T.** Tympanic membrane. **R.** Annulus tympanicus. **E.** Eustachian tube. **m.** Mouth. **h.** Hyoid. **a.** Upper jaw. **b.** Lower jaw.

two half-hoops of cartilage united by ligament at their upper ends to the vertebral column, and by their lower ends to the sternum or breastplate. Each is divided by the articular cavity for the limb bone into an upper or **Scapular**, and a lower or **coracoid** portion.

The scapular part consists of a broad, curved, cartilaginous plate above, the **supra-scapula**, and a lower narrower bony portion, the **scapula**, which runs down to the articular cavity. The **coracoid** consists of an anterior and posterior portion separated by the **coracoid foramen.** The anterior part is the **precoracoid,** a slender bar of cartilage which is covered by the **clavicle,** a membrane bone. The posterior part, or **coracoid** proper, is a stout bone narrow in the middle, and stretching from the articular cavity to a wide attachment to the sternum. The sternum is a median segmented flattened rod originally composed of two pieces which have fused together in the middle line. The anterior segment, or **episternum,** is a plate of cartilage projecting in front. The second segment, the **omosternum,** is a narrow median bone projecting in front of the coracoid. The third segment is composed of two lateral cartilaginous pieces, the **epicoracoids,** fused together in the middle line and attached at their outer surfaces to the coracoid. The fourth segment, the **sternum** proper, is a broad bony rod projecting behind the coracoid region. The fifth segment, the **xiphisternum,** is a flat plate of cartilage.

The **pelvic girdle** of the frog is much modified in association with the jumping habits of the animal. Instead of being at right angles, it makes an acute angle with the backbone. On the outer surface at each side the girdle is divided by the **acetabulum,** the articular surface for the limb, into an upper or **iliac** portion, and a lower or **ischio-pubic** portion.

The **ilium** forms the upper portion of the arch at each side. Its anterior end is attached to the **sacral rib.** Its posterior end forms part of the acetabulum, and the two ilia meet together at their inner posterior ends to form the iliac symphisis. The ilium is bony.

The ischio-pubic or ventral portion of the girdle consists of a posterior part, the ischium corresponding to the coracoid, and an anterior portion, the pubes corresponding to the pre-coracoid. These are, however, closely united together, and with the hinder end of the ilia.

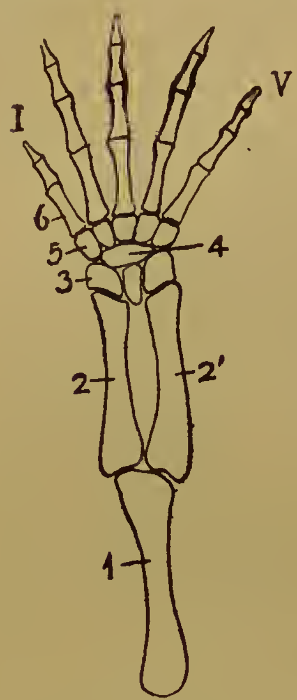

FIG. 60.—Diagram of Vertebrate Limb: digits I–V.—Leg: **1.** Femur. **2.** Tibia. **2'.** Fibula. **3.** Tibiale, intermedium, fibulare. **4.** Centrale. **5.** Distal tarsals. **6.** Metatarsals. — Arm: **1.** Humerus. **2.** Radius. **2'.** Ulna. **3.** Radiale, intermedium, ulnare. **4.** Centrale. **5.** Distal carpals. **6.** Metacarpals.

The **ischium** forms the posterior part of the ventral division of the girdle at each side. The ischia form a large part of the acetabulum, and the two are united in the middle line to form the ischial symphisis.

The **pubes** form the anterior portions of the ventral division of the girdle. They are fused in the middle line in the pubic symphisis, and they form a very small part of the acetabula.

Skeleton of the limbs. The limbs of all vertebrates which possess them are built on the same general plan. The typical structure consists of an upper rod, the **humerus** (in arm) or **femur** (in leg) articulated at the upper end with the girdle. Then follow two parallel rods, the **radius** (arm), or **tibia** (leg), on the side next the body, and the **ulna** (arm) or **fibula** (leg) on the side remote from the body. Next come three rows of small bones, **carpals** (wrist), **tarsals** (ankle). The first row has three bones, the **radiale** or **tibiale**, at the end of the radius or tibia, the **intermedium**, then the **ulnare** or **fibulare**, at the end of the **ulna** or **fibula**. The second row consists of one bone, the **centrale**; the third row of five bones, the **distal carpals** (wrist), **distal tarsals** (ankle). Then follow the digits of the hand or foot, numbered one to five, beginning with the thumb or great toe, which is opposite the radius or tibia on the inside. Each digit has a long bone, the **metacarpal** (hand), **metatarsal** (foot), and a number of short joints, the **phalanges**.

The arms or legs of all vertebrates are based upon this type. In a very few cases the number of digits is increased, the increase taking place on either side. In most cases the change from the type consists in the reduction of the number of the digits and in the fusion of the bones in some of the rows. In order to compare any animal with the type it should be put in the primitive position. For instance, in the case of man, the primitive position of the limbs is attained when one stoops down on the hands and feet, as if one were licking up water from a pool. Then the elbows project outwards and backwards, the thumbs point forwards, being on the inside of the hands, and the radius also lies on the inside of the arm.

Skeleton of the forelimb. 1. **Humerus.** The proximal end or head is enlarged, and articulates with the glenoid cavity of the pectoral girdle. The distal end has a rounded surface, with which the forearm articulates. 2. The **radio-ulna** corresponds to the typical radius and ulna fused into a single bone. The outer side corresponding to the ulna projects behind the articulation with the humerus as the olecranon or elbow process. The three rows of carpals are reduced to two. The first row, or **proximal carpals**, has three bones, the second or distal row has also three, the outer one being very large. There are five metacarpals. The first, corresponding to the thumb, is very small and has no phalanges; it articulates with the inner distal carpal. In the living condition it does not protrude beyond the skin, and so the frog is said to have no thumb. The second metacarpal is large, and articulates with the second distal carpal. It has two phalanges, and forms the first finger of the frog, which in the male bears a large glandular swelling in the breeding season. The third, fourth, and fifth fingers have all stout metacarpals attached to the large distal carpal, and bear respectively two, three and three phalanges.

Skeleton of the hind limb. The **femur** is the bone of the thigh. Its rounded head fits into the acetabulum of the pelvic girdle forming the hip-joint. Its broader distal extremity articulates with the bone of the lower leg. The **tibio-fibula**, like the bone of the forearm, is a single structure corresponding to a fused tibia and fibula.

The ankle also is reduced to two rows of bones. The upper or proximal row consists of two long bones separated from each other in the middle, touching at the ends. The bone on the inner or tibial side is the **astragulus**, that on the outer side is the **calcaneum**, corresponding to the heel bone of higher animals. The distal row of tarsals consists of two very small bones. There are five digits, number one, the great toe being on the inner side, and actually being the smallest of the five. Each has a strong **metacarpal** bone which is followed by respectively two, two, three, four, and three phalanges.

In addition there is a **supernumerary** digit consisting of

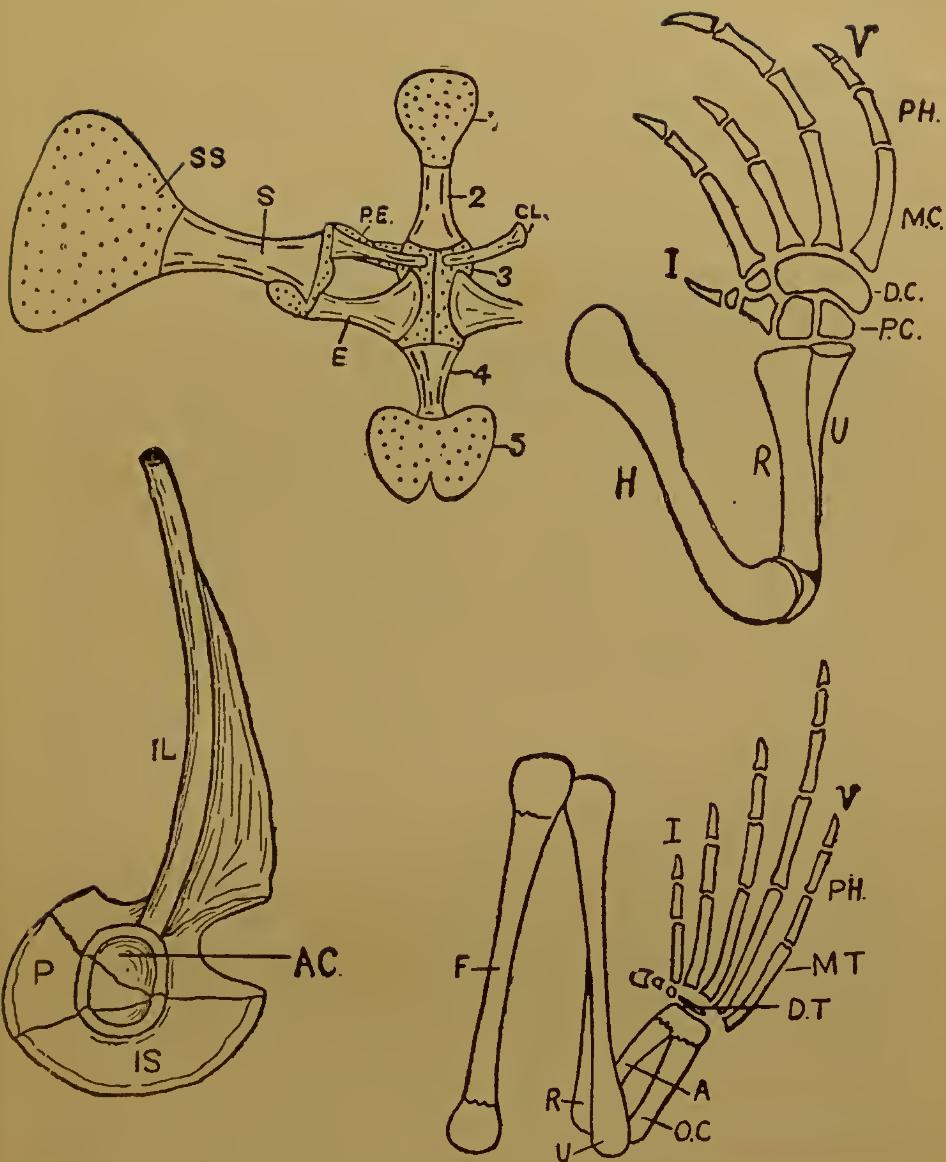

FIG. 61.—Skeleton of Girdles and Limbs of Frog. Upper left-hand figure: Pectoral Girdle. **SS.** Supra-scapula. **S.** Scapula. **P.E.** Pre-coracoid with clavicle (**CL.**) overlying it. **E.** Coracoid proper. **1.** Epi-sternum. **2.** Omosternum. **3.** Epicoracoid. **4.** Sternum proper. **5.** Xiphisternum.—Upper right-hand figure: Arm and Hand of right side, dorsal view. **H.** Humerus. **R. U.** Radio-ulna. **P.C.** Proximal carpals. **D.C.** Distal carpals. **M.C.** Metacarpals. **PH.** Phalanges. **I.** First digit with no phalanges.—Lower left-hand figure: Pelvic girdle of left side. **IL.** Ilium. **P.** Pubis. **IS.** Ischium. **AC.** Acetabulum.—Lower right-hand figure: Leg and Foot of right side, dorsal view. **F.** Femur. **RU.** Tibio-fibula. **A.** Astragulus. **O.C.** Os calcis. **D.T** Distal tarsals. **MT.** Metatarsals. **PH.** Phalanges.

two short joints, on the inner side more internal than the great toe.

DISSECTION OF THE FROG.

This should be performed under water, the frog being laid on its back and fastened to the bottom of the dissecting dish by pins through the limbs. The skin, which is loosely adherent to the underlying parts, being separated from them by the **lymph spaces**, should be dissected off the ventral surface of the body. The position of the pectoral girdle should be determined, and the anterior abdominal vein seen through the body-wall running along the mid-ventral line. The abdominal cavity must be opened by a slit parallel to this vein, as close to it as may be done without injury, and the cut should be continued forwards through the pectoral girdle, which may be cut with scissors, to the jaw, and backwards to the hinder end of the body. Next, the abdominal vein must be carefully separated from the body-wall overlying it, and then the body-wall at each side should be pinned back, short transverse incisions being made at the posterior end of the original longitudinal incision. The **abdominal cavity**, as in the dog-fish, is the cœlomic cavity, and the viscera are suspended by mesenteries in it exactly in the same fashion, in reality lying outside the cavity. The heart, enclosed in a delicate pericardium, which is a separated part of the cœlome, lies in the anterior region. The **liver** is a large bilobed organ, dark-red in colour, lying partly behind, partly at the sides of the heart. At the sides of the heart and dorsal to the liver, so that they are concealed by it from the ventral surface, are the **lungs**, a pair of thin-walled, lobulated sacs which may be dilated with air by blowing through a fine tube passed through the larynx from the mouth. Immediately behind the liver may be seen the **fat-bodies**, two bright yellow tufts attached to the dorsal wall of the body-cavity behind the kidneys, and specially conspicuous in autumn. Behind these, the greater part of the cavity is occupied by the coils of the small intestine, while, at the posterior end, the bladder projects as a transparent thin-walled sac which may be inflated by blowing through a tube passed into the cloaca.

In males, which may be recognised before dissection by the glandular swelling on the index finger, the **testes** appear as a pair of yellow, oval bodies, attached to the dorsal wall of the abdominal cavity. In females, which are usually more bulky in the abdominal region, the greater part of the abdominal viscera are concealed by the **ovaries**, two large masses of small black and white eggs, and the **oviducts**, two much convoluted, white tubes with thick walls, lying at the sides of the abdominal cavity.

The **peritoneum** is the lining membrane of the body-cavity. It is pigmented in places and, as in the dog-fish, inpushings of its walls, caused by the protrusion of the organs into the cavity, form the mesenteries.

THE ALIMENTARY CANAL.

The **œsophagus** is a short wide tube opening into the stomach, which is a curved, dilated tube, not bent to form two limbs as in the dog-fish, and separated from the intestine by a **pyloric constriction.** The **intestine** is much longer and more slender proportionately to the size of the animal, and has no spiral valve, the necessary extent of absorbing surface being given by the increase in length. Posteriorly it passes into the dilated **rectum**, which opens into the cloaca. The **liver** has a right and left lobe and a large gall-bladder.

The **bile duct** is a slender duct which arises both from the gall-bladder and from the right and left lobes of the liver. It runs through the substance of the **pancreas** to open into the **duodenum**, or first part of the intestine, half-way between the pylorus and a fibrous ligament which fastens the duodenum to a small separate lobe of the liver lying above the gall-bladder.

The **pancreas** is a whitish, irregularly lobed mass which lies between the stomach and the duodenum. It has numerous ducts, too small to be seen in dissection, which open into the bile duct, and so convey the pancreatic secretion to the intestine.

The **spleen** is a small, bright red organ lying in the mesentery near the anterior end of the rectum.

THE ORGANS OF RESPIRATION AND CIRCULATION.

The condition of these organs in the adult frog, and the modified forms of them present in reptiles, birds, and mammals, can be best understood from a consideration of the changes which take place when the tadpole, the fish-like stage, passes into the adult stage. The condition in the tadpole is very similar to that in the dog-fish. At each side of the head six gill-bars appear. The first of these is the mandibular bar, and, as in the dog-fish, this gives rise to the upper and lower jaws. The second is the hyomandibular bar, the succeeding four are branchial bars, one pair less than in the dog-fish. The tip of the hyomandibular bar forms most probably the columella, while the lower part unites with the remains of the branchial arches to form the hyoid apparatus of the adult frog.

There are five gill-slits. The first, corresponding to the spiracle, never opens to the exterior, and the membrane closing its end is generally believed to become the tympanic membrane, while the cavity leading into the front part of the alimentary canal forms the eustachian tube. The four succeeding gill-clefts close up, being covered by an opercular membrane which grows forwards over them from the hyo-mandibular arch.

While the gill-slits are open, the heart, as in the dog-fish, consists of an S-shaped contractile tube, the dorsal and posterior aperture of which receives blood from the veins, while the ventral and anterior end is continued forward as a truncus arteriosus, which gives rise to four afferent branchial vessels running up the four branchial bars to supply the gills. From these, the blood is collected, as in the dog-fish, by four pairs of efferent branchial vessels which unite behind to form a systemic aorta, coursing along the body immediately under the backbone. From the front part of the ventral surface of the alimentary canal a pair of pouches grow out backwards and form the lungs. They are supplied with blood from a special vessel which leaves the efferent vessel of the fourth arch at each side.

The metamorphosis, or change to the adult condition, occurs rather suddenly. The blood, instead of passing through the capillaries in the gills, passes directly from the afferent to the efferent arches by short straight vessels which connect them, and the gills and the capillary system shrink up. There are, therefore, at each side four arches corresponding to the afferent and efferent vessels, passing from the truncus arteriosus to the systemic aorta. The first, or most anterior of these arches, gives rise to the carotid arteries of each side, which already before the metamorphosis have become separated into an external and an internal carotid. The second arch, meeting its fellow of the other side, forms the systemic aorta of the adult. The third arches disappear, while the fourth arches loose their connection with the systemic aorta, and are continued as the branches to the lungs which form the pulmonary arteries of the adult. Meantime the originally S-shaped heart becomes broken up into chambers by partitions.

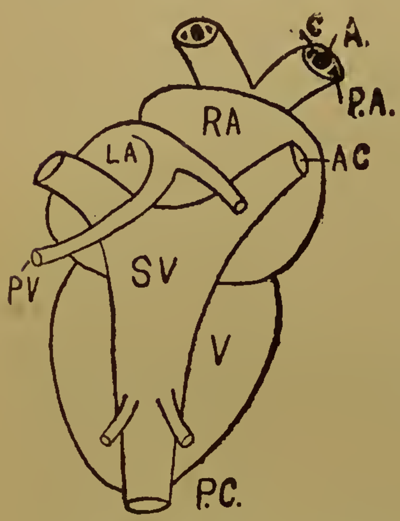

FIG. 62.—Heart of Frog; dorsal aspect. **V**. Ventricle. **LA**. Left auricle. **RA**. Right auricle. **SV**. Sinus venosus. **P.C**. Posterior vena cava with hepatic veins. **PV**. Pulmonary veins. **C**. Carotid. **A**. Sysmatic aorta. **P.A**. Pulmonary artery.

The heart of the adult must be examined by opening the pericardium and dissecting it away from the origins of the great vessels. Examination of the interior cavities must be deferred till the vessels have been examined, when the heart may be removed and its chambers slit open under water and washed free from blood.

The **two auricles** occupy the dorsal and anterior part of the heart; they are thin-walled and closely applied to each other and to the ventricle, round which they are wrapped. The **ventricle** is the conical posterior part which is continued forwards as the **truncus arteriosus**, from which the great vessels arise. The **sinus venosus** is a thin-walled sac on the dorsal surface behind the auricles ; the **three venæ cavæ** open into it.

When the sinus venosus is cut open, it is seen to lead into the right auricle by a wide opening in its anterior end. This opening is partially guarded by a pair of valves. The venous blood received by the sinus passes into the cavity of the right auricle, from which it is driven, by contraction of the irregular net-work of muscles in the wall, into the right side of the ventricle. The left auricle is separated from the right auricle by a very thin partition. It receives the oxygenated blood returned from the lungs by the pulmonary veins, and, by contraction of its wall, which, like the right auricle, is provided with a net-work of muscle, the blood is driven into the left side of the ventricle, through an opening separated from the right auriculo-ventricular opening by a thin valve which hangs down into the cavity of the ventricle. The ventricle has a thick, muscular wall, the inner part of which is spongy. The ventricle opens into the **pylangium,** or first part of the truncus arteriosus, by a circular aperture guarded by three pouch-like valves, the openings of which are turned away from the ventricle so that if blood, pumped into the truncus from the ventricle, attempted to flow back it would run into these pockets, and bulging them out would close the aperture.

The inner wall of the pylangium has a spiral valve attached along its length and hanging freely into the cavity. The pylangium is continued forwards into the **synangium**, which is formed by the united bases of the arterial trunks. The aperture of the synangium into the pylangium is guarded by three pocket-shaped valves, the openings of which are directed away from the heart. The apertures into the pulmonary arteries are immediately behind these valves. The wide cavity of the synangium forks in front, and is continued as the systemic aortic arch of each side. A small projecting tongue hangs backwards into the cavity from the angle of the fork, and the small apertures of the carotid arteries lie close together on the under surface of this tongue.

The mechanism by which the streams of mixed blood coming from the ventricle are separated to their proper trunks is very complicated. When the ventricle contracts the truncus arteriosus is still relaxed, and the impure blood from the right side of the heart buoys up the spiral valve and reaches the lower or pulmonary openings. When the contraction has gone on further and the pure blood from the left side is entering it, the truncus begins to contract and the free anterior edge of the spiral valve partly occludes the apertures into the pulmonary arteries, and the purer stream is directed spirally round the valve forwards to the aortic arches and the carotids.

The Venous System. This should be dissected before the arteries. The veins can be distinguished by their thinner walls, through which the contained blood is visible.

The right and left **venæ cavæ** open into the sides of the sinus venosus, and are formed by the junction of three similar veins on each side.

1. The **external jugular** vein is formed by the junction of the lingual vein from the tongue and floor of the mouth, and the **mandibular** vein from the lower jaw.

2. The **innominate** vein is formed by the **internal jugular** vein from the interior of the skull, and the **subscapular** vein from the back of the arm and shoulder.

3. The large **subclavian** vein is formed by the **musculo-cutaneous** vein from the skin of the side and back, and the **brachial** vein from the arm.

The **posterior vena cava** is a median vein which runs from between the kidneys from which it returns the blood to the dorsal part of the liver through which it runs without breaking up. On its emergence, it is joined by a right and left **hepatic** vein and then enters the posterior end of the sinus venosus. Between the kidneys and liver it receives at each side a vein from the genital organ.

The Hepatic Portal System. The greater part of the blood from the hind limbs is returned by a **femoral** vein at either side. When these reach the pelvic region they break up into a dorsal and a ventral branch. The ventral branches unite and form the **anterior abdominal** vein which runs forward to the level of the liver, where it divides into right and left branches which break up in the right and left lobes of the liver. The **hepatic portal** vein is a large vessel which returns the blood from the spleen and alimentary canal. It divides into a small branch which breaks up in the left lobe of the liver and a large branch which joins the anterior abdominal vein before that splits into right and left branches.

The Renal Portal System. The dorsal divisions of the femoral veins receive each a **sciatic** vein from the back of the thigh and small, dorso-lumbar veins from the body-wall; then they run forward to the outer side of the kidney and break up in that organ.

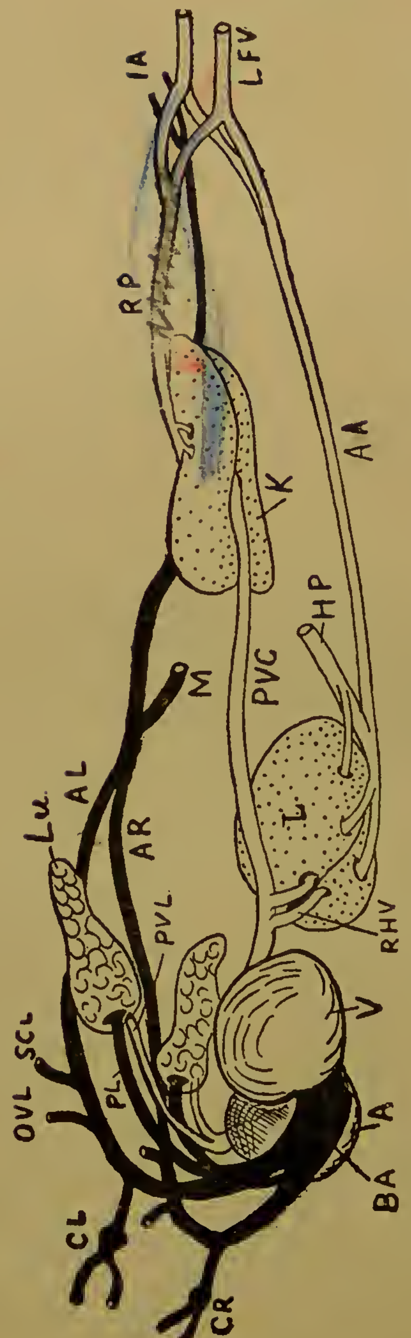

Fig. 63.—Great Vessels of Frog as seen from the left side. Arteries, black; veins, white. **V.** Ventricle. **A.** Auricle. **B.A.** Truncus arteriosus. **Lu.** Lung. **L.** Liver. **K.** Kidney. **CR.** Right common carotid. **CL.** Left common carotid. **PL.** Left pulmonary artery. **OVL.** Left occipito-vertebral artery. **SCL.** Left subclavian artery. **AL.** Left systemic aorta. **AR.** Right systemic aorta. **M.** Cœliaco-mesenteric artery. **IA.** Iliac artery. **PVL.** Left pulmonary vein. **PVC.** Vena cava posterior. **HP.** Hepatic portal vein. **AA.** Anterior abdominal vein. **RHV.** Right hepatic vein. **RP.** Renal portal vein. **LFV.** Left femoral vein.

The **pulmonary** veins return the blood which has been oxygenated in the lungs to the left auricle.

The Arterial System. The **truncus arteriosus** divides into three arches at each side.

The **carotid arch** is the most anterior, and runs forwards for about one-tenth of an inch, when it gives off a small **lingual artery** to the tongue. Immediately beyond this there is a small spongy expansion of its wall, called the **carotid gland.** Beyond this a small strand of tissue, the **ductus Botalli**, runs back to the systemic arch; it is the remains of the original connection of the first branchial efferent vessel with the systemic aorta, and usually is impervious, though as an abnormality it may remain open. The carotid runs forwards by the side of the œsophagus, and divides into the **external carotid** which supplies the mouth and the orbit, and the **internal carotid** which enters the skull and supplies the brain.

The second division of the truncus at each side forms the **aortic arch.** Each gives off a **laryngeal artery,** several small **œsophageal arteries,** an **occipito-vertebral artery,** and finally a large **subclavian artery** which supplies the shoulder and forelimb. Then the two aortic arches meet over the alimentary canal nearly at the anterior level of the kidneys, and form the **systemic aorta.** From this, immediately after the junction, arises a large median **cœliaco-mesenteric artery** which divides into a **cœliac** branch for the stomach, liver and gall-bladder, and a **mesenteric artery** which divides into anterior and posterior branches for the anterior and posterior parts of the intestine, and a short **splenic branch** for the spleen. While passing between the kidneys, the aorta gives off several paired branches to them and to the genital organs, **lumbar**

arteries to the body-wall, and a **hæmorrhoidal artery** to the rectum. When it emerges from between the kidneys it divides into a right and left **iliac artery**, each of which, after giving off branches to the bladder and to the ventral body-wall, runs down the leg as the **sciatic artery**.

The **pulmo-cutaneous arch** is the third division of the truncus at each side. At the most anterior part of its course before it bends down to the lung each gives off a large **cutaneous branch** which is distributed to the outer skin, forming a conspicuous branching system. During winter, while the frog is hibernating in the mud at the bottom of ponds and ditches, this skin-branch is the chief means by which oxygen is obtained.

As in the dog-fish, the blood consists of a fluid plasma in which are present white amœboid corpuscles, and oval nucleated red corpuscles, the colour of which is due to the presence of hæmoglobin.

THE URINO-GENITAL SYSTEM.

In the frog, as in the dog-fish, the genital organs appear as a pair of thickenings in the dorsal wall of the cœlome: The excretory organs arise as a pair of **head-kidneys**, each head-kidney or pronephros consisting of three nephridia opening by funnels into the anterior part of the cœlome, and leading into a pronephric or segmental duct which runs down the body, unites near the posterior end with its fellow of the other side, and then opens into the cloaca. Soon after the tadpoles are hatched, the **mesonephros** appears as a number of segmentally arranged nephridia opening into the body cavity by ciliated funnels and into the segmental duct by their other extremities. At the time of the metamorphosis, the head-kidney aborts and the segmental duct splits longitudinally, forming an anterior part which extends forward in the body nearly to the position of the original head-kidney and opens behind into the second part. That again remains in connection with the mesonephros, and opens behind into the cloaca. The anterior division of the original duct undergoes no alteration, in the adult male. In the female it acquires a large opening into the body-cavity at its anterior end, and becomes the **oviduct**. The second or mesonephric part of the duct becomes the **ureter** in both sexes, there being no true metanephros established. In the male, as in the dog-fish, the sexual products pass to the exterior through the mesonephric ureter.

The Adult Female. The **ovaries** are a pair of dark masses lying in folds of the peritoneum in front of the kidneys. In spring and early summer, after the eggs have been discharged, the ovaries are small ; in autumn and winter they increase in size, and numbers of ripe eggs are detached from them and leave the body-cavity to enter the oviducts by the cœlomic funnels. They accumulate in the lower ends of the oviducts, forming large masses which are pressed out from the cloaca of the female by the male, and the eggs are fertilized in the water.

The **oviducts** are a pair of much convoluted thick-walled tubes opening behind into the cloaca by two separate apertures on the dorsal wall, and in front by funnels into the cœlome close to the anterior ends of the lungs.

The **kidneys** are a pair of elongate, reddish, flattened bodies lying close to the middle line on each side of the backbone. The ureters are a pair of slender white tubes running from the outer edges of the posterior part of the kidneys to the dorsal wall of the cloaca; they open immediately behind the oviducts and opposite the opening of the bladder which is on the ventral wall of the cloaca. In the living frog the bladder contains fresh water, not excretory products.

The Adult Male. The **testes** are a pair of rounded organs lying on the ventral surface of the kidneys. The **vasa efferentia** are a number of small tubes leading from the testes to the inner edges of the kidneys into which they pass, enabling the spermatozoa to be discharged through the ureters.

The **kidneys** are similar to those of the female.

The **ureters,** which function also as **vasa deferentia,** run from the outer side of the kidney to the dorsal wall of the cloaca, into which they open opposite the opening of the bladder.

The **vesicula seminalis** is a dilatation of the outer wall of the vas deferens or ureter of each side, between the kidney and the cloaca.

THE NERVOUS SYSTEM.

This is essentially similar to that of the dog-fish, and it should be compared carefully with the figures and notes made while that was being dissected. Owing to the greater difficulty of dissecting the cranial nerves of the frog, the elementary student is recommended not to attempt them until he has thoroughly mastered their arrangement in the dog-fish. The dorsal surface of the brain should be exposed by removing the fronto-parietals, and continuing the opening by removing the dorsal surface of the occipital region and of the atlas. Examination of the ventral surface must be deferred until the cranial nerves have been dissected.

The divisions of the brain are the same as in the dog-fish. The **olfactory lobes** form the most anterior part. They are fused together in the middle line on the dorsal surface and from their anterior ends arise the **olfactory nerves**.

The **prosencephalon** is clearly divided into two cerebral hemispheres, which diverge behind.

The **thalamencephalon** is a small space, partly over-lapped by the ends of the cerebral hemispheres in front. It is covered by a vascular **choroid plexus** through which the stalk of a small **pineal body** passes. The pineal reaches to the under surface of the skull.

The **mesencephalon** has a pair of very large **optic lobes**, and from the region immediately behind them the **fourth nerves** arise from the dorsal surface.

The **cerebellum** is an exceedingly small transverse band of tissue stretching across the anterior part of the fourth ventricle.

The **medulla oblongata** is relatively large, broad in front, and tapers behind as it passes into the spinal cord. The fourth ventricle is roofed over by a thin vascular membrane which is usually torn in dissection. From the sides of the medulla the fifth, seventh, eighth, ninth and tenth nerves may be seen arising by three roots. There are no restiform bodies.

On the ventral surface, the **optic chiasma**, as in the dog-fish, occupies the ventral surface of the thalamence-phalon. Behind it is a bilobed **infundibulum** from which the pituitary body extends backwards over the anterior part of the medulla, as an elongate, rounded mass. Between the pituitary body and the infundibulum the third nerves arise from the ventral surface of the brain, and the sixth nerves arise from the ventral surface of the anterior part of the medulla.

The **crura cerebri** are two diverging masses of fibres seen behind the optic lobes. They connect the cerebrum with the medulla and spinal cord.

The cavities of the brain are similar to those in the dog-fish, and receive similar names.

The Peripheral Nervous System. As in the dog-fish the **spinal nerves** arise by dorsal ganglionated roots and ventral motor roots. These unite outside the spinal canal. The **hypoglossal,** or first spinal nerve, runs forwards to the muscles of the tongue and floor of the mouth, showing that the process of cephalisation has gone on further in the frog than in the dog-fish. A notable condensation of the segmentation of the spinal nerves occurs in two regions. The second and third spinal nerves unite together to form at each side a large **brachial nerve** for the shoulder and arm. The seventh, eighth, and ninth spinal nerves similarly unite at each side to form a large **sciatic plexus** which supplies the hinder limb and a large portion of the posterior region of the body.

The Cranial Nerves.

1. The **olfactory nerve** supplies the nasal organ.

2. The **optic nerve,** as in the dog-fish, is an outgrowth from the brain, the anterior end of which became first the optic vesicle and then the retina.

3, 4, and 6. The **third nerve,** the **fourth nerve** and the **sixth nerve** have origin, course, and distribution as in the dog-fish, but from their minute size are difficult to dissect in the frog.

5. The **fifth nerve** is the most anterior of those arising from the side of the medulla. It runs forwards within the cranial cavity to the region in front of the auditory capsule. It then expands to form a large **gasserian ganglion**, and immediately afterwards passes through the skull-wall into the orbit, and divides into two main branches. The first, or **ophthalmic branch**, runs along the inner wall of the orbit, passes in two branches through the walls of the nasal capsule, and is distributed to the forepart of the head. The second or **maxillo-mandibular** branch runs outwards behind the eyeball and divides to supply the upper and lower jaws.

7. The **seventh** or **facial nerve** arises from the side of the medulla next behind the fifth. It runs forward parallel to the fifth nerve to the gasserian ganglion with which it is connected, and then emerges into the orbit close behind the fifth. There it divides into a **palatine** branch which runs forwards to the roof of the mouth, and a **hyomandibular** branch which forks under the tympanic membrane, first giving off twigs to that and to the angle of the mouth. The anterior branch of the fork, or **ramus mandibularis**, runs along the floor of the mouth just inside the edge of the lower jaw ; the second branch, or **ramus hyoideus**, runs along the floor of the mouth deeper down and supplies the muscles of the hyoid.

8. The **auditory nerve** arises immediately behind and apparently but not really fused with the seventh ; it passes at once into the auditory capsule.

9 and 10. The **ninth**, or **glossopharyngeal**, and the **tenth**, the **pneumogastric** or **vagus** arise together from

the side of the medulla more posteriorly. The two emerge together from the skull behind the auditory capsule. The ninth divides, and the **anterior** branch, which runs round the posterior end of the auditory capsule, joins the seventh nerve in front of the columella ; the **posterior** branch runs downwards and forwards to the pharynx, and then supplies several of the muscles of the tongue.

The tenth nerve enlarges to form a ganglion immediately outside the skull ; it then runs backwards through the body giving off nerves to the muscles of the back, and several important nerves to the viscera. These are given off from the point where the vagus reaches the pulmonary artery. The **laryngeal,** or recurrent branch of the vagus, loops round the pulmonary artery close to its origin from the truncus, and then runs forwards again, parallel to the vagus until it enters the larynx in the middle line. The **cardiac branch** passes dorsal to the pulmonary artery and reaches the sinus venosus, passing over the vena cava anterior. The branches of each side unite and pass into the auricular septum. The **pulmonary** branches run along the pulmonary arteries to the lungs. The **gastric** branches, two at each side, pass to the walls of the stomach.

The Sympathetic System. This consists at each side of a **longitudinal ganglionated trunk** extending from the gasserian ganglion in the skull to the posterior spinal nerve. The ganglia are connected with the spinal nerves and give off numerous networks to the viscera, the chief of which are a **cardiac plexus** over the auricles and the roots of the great vascular trunks, and a **solar plexus** over the stomach.

The longitudinal sympathetic cord at each side starts from the gasserian ganglion. It runs backwards and emerges from the skull with the ninth and tenth nerves, being connected with the ganglion of the vagus. It then runs backwards alongside the vertebral column, and has a ganglion in connection with each spinal nerve and several in connection with the tenth spinal nerve. In the posterior region of its course it is closely attached to the side of the systemic aorta.

THE SENSE ORGANS.

In the tadpole there is a lateral line with definite sense organs, the sensory cells of which are surrounded by projecting cuticular tubes. In the adult these have degenerated into patches of mucus-forming cells. But, irregularly placed on the skin, especially on the fingers and toes, there are small touch bodies, each of which consists of a transparent cluster of flattened cells, richly supplied by nerve fibres.

The mucous membrane of the tongue and roof of the mouth contains numerous **taste bodies**, each of which consists of several cells with forked projecting extremities and inner ends in connection with nerve fibrils.

The **eye** is essentially similar to that of the dog-fish. But the cornea is more curved, and between the cornea and the lens is a small chamber containing aqueous humour. The choroid coat has no tapetum.

The **nasal organs** are proportionately smaller and must be examined by microscopic sections. The cavity is constricted into three divisions, the outer of which communicates with the nostrils, the inner by the internal nares with the buccal cavity.

The Ears. The **internal ear** is essentially similar to that of the dog-fish, but there is no aqueductus vestibuli in the adult, and the **sacculus** is more distinct from the utriculus. In the dog-fish the auditory capsule is separated from the outer world only by the outer skin. In the frog the capsule is more deeply sunk in the side of the head. The upper part of the hyomandibular gill-cleft, which opens below into the mouth as the eustachian tube and which is closed over by the tympanic membrane, forms a middle or accessory auditory chamber. The inner wall of this is formed by the outer wall of the auditory capsule, and in this there is a hole into which the head of the columella fits. The columella stretches across to the tympanic membrane and its outer end is attached to that. Thus vibrations of the tympanum are transmitted along the columella and by its inner end are transmitted to the inner ear. In higher animals this middle chamber in turn is sunk into the side of the head and so the tympanic membrane is at the bottom of a cavity, the external auditory meatus, which is surrounded by the shell of the ear. Thus in man, the frog and the dog-fish, three stages of elaboration are shown.

CHAPTER XVIII

EMBRYOLOGY

THE animals we have examined form in a sense an ascending scale. The frog is higher than the dog-fish, the dog-fish than the worm, the worm than hydra, and hydra than amœba. No doubt each of them is equally fitted to the circumstances in which it lives, and, so far as what is called **adaptation to its environment** goes, each is equally well off, and the frog, for instance, would be as unable to occupy the place of amœba as amœba would be for the manner of life of the frog. But in the type of its structure, each of them forms an improvement and advance on the one next below. Hydra is a colony of single cells which are specialised and arranged so as to form the cœlenterate type of structure. The cœlomate type is an extension and improvement on the cœlenterate, while among the cœlomata the vertebrate type is composed by a series of alterations of and additions to a simple invertebrate type. Among the vertebrates we have seen that the type on which the frog is built is in many respects simply an improved and altered edition of the dog-fish type. It must be remembered, however, that we have examined only three or four out of the multitude of forms composing the animal kingdom; and each kind of animal in addition to its ground-plan, its typical structure, has an immense number of individual characters. It is only after the examination of a larger number of animals that it is possible in individual cases to separate the structure of the animals that are individual peculiarities from the structures which characterise its type. Every one has seen the immense blocks of buildings divided into hundreds of sets of flats that are now being erected in our large cities. There are generally only three or four types of suites of rooms among all these sets. But before they are occupied one may see a legend on a placard stating that these flats will be "papered and decorated to suit the wishes of the tenants." When this has been done the different tenants have their own ideas of furniture, of arrangement of pictures, and so forth, and when the whole block is occupied perhaps only an architect could discern among all the diversities of appearance the three or four ground-plans of structure that exist. The animal kingdom in many respects is like this. But the amœba, the hydra, the earthworm, the dog-fish, and the frog, have been selected because they are representatives of the leading types of structure that have been found to exist among animals.

The embryological development of an animal is the series of changes through which it passes from its first formation to its arrival at the adult type. It will be remembered that even in the protozoa there were instances of changes of this nature. For instance, when Vorticella reproduces by spore formation, the tiny, naked, nucleated mass of protoplasm that emerges through the ruptured spore-wall bears no resemblance to the adult condition. It feeds and grows, develops cilia and swims about. At last, however, it forms a pharynx, peristome, and disc, and, becoming fixed by a contractile stalk, settles down as an adult vorticella. However, the young cell creeping out of the spore is as much a cell as the fully formed complicated animal. In the embryological development of all the metazoa the set of changes consists not only in the specialisation of cells, but in their multiplication and arrangement in definite ways. It is now known that animals in the course of their development pass through stages corresponding to the main types of structure below them. Thus the sexual development of all the metazoa begins with the union of a male cell, or spermatozoon, with a female cell or ovum. This corresponds to the conjugation of two protozoa before spore formation. Next, by division of the cell resulting from the fusion of the male and female cells, a mass of cells is formed sometimes solid, sometimes hollow, and this stage, the blastosphere, corresponds to a colony of protozoa. Next the blastosphere turns into a two-layered form such as the gastrula. The cœlenterate animals do not rise beyond this in type. Hydra is a simple modification of it, and the other cœlenterates are simply complications of the gastrula type. Next, the gastrula becomes cœlomate by the formation of the middle layer and the cœlome. Then a number of different courses may be followed. In a typical invertebrate a leading change consists in the concentration of the ectodermal nervous layer into a brain, a ring round the œsophagus, and a ventral ganglionated chain. In the typical vertebrate the ectodermal nervous layer becomes concentrated into a brain and dorsal nervous tube, while a skeletal structure, the notochord, appears between the gut and the dorsal nerve tube. At the same time the front end of the alimentary canal becomes modified in connection with respiration by the formation of gill-slits.

We shall now consider the essential elements of the process of development in greater detail, keeping specially in mind the vertebrate type, because, as the highest, it includes the leading features of lower types.

Naturally we begin with the sexual cells. The testes and ovaries are situated in different places in different animals. They are among the earliest organs that appear in development. In some cases the fertilised egg-cell at its first division separates into one cell that forms the general body of the animal and one cell that, by subsequent division, forms the ovary or the testis. In vertebrates, however, the genital organs are not visible, perhaps not actually present as cells until the middle layer of cells has appeared. The material beginning of the ovary or testis consists of a few cells with large nuclei in the dorsal wall of the cœlome.

The testis of an adult consists almost always of an organ composed of a number of tubes, the hollow walls of which are lined by cells. As these give rise to spermatozoa they may be called sperm-mother-cells (Fig. 64.1). Each sperm-mother-cell possesses a nucleus with a definite number of chromosomes. In the case represented there are four of these, and at 2 they have divided. The sperm-mother-cell divides by karyokinesis first into two cells, and then each of these into two. But in one division no longitudinal splitting of the chromosomes occurs, so that each of the four cells possesses only two of the original four chromosomes. Each in addition possesses a centrosome. These four cells are called spermatoblasts, or young spermatozoa, and by a change of shape they turn into fully-grown spermatozoa. The chromosomes pass into the resting condition, and in vertebrates form a long, narrow, rather flattened mass which is known as the head of the spermatozoon. The centrosome is attached to one end of this, and is known

FIG. 64.—Diagram of Spermatogenesis. **1**. Primitive sperm-mother-cell from wall of sperm-tube. **2**. Ripe sperm-mother-cell with eight chromosomes. **3** and **4**. First or equal division. **5** and **6**. Second reducing division. **a**. **b**. **c**. **d**. Forms of adult spermatozoa. **a**. Crustacean. **b**. Man. **d**. Newt. **c**. Insect.

as the middle piece of the spermatozoon. Finally the protoplasm passes entirely to the end of the centrosome which is not next the nucleus or head, and forms the long waving tail by which the spermatozoon is able to move actively in fluids. The sperm-cells in this condition are ripe and ready to leave the body of the male. In lower animals they are most often discharged directly into the water and swim about until they meet the egg-cell, which, however, usually remains in the body of the parent. In higher animals usually they are passed directly into the body of the female by special intromittent organs, and the act of copulation is this process. The sperm-cells are the smallest cells of animal tissues, and they are produced in immense quantities by the males. The seminal fluid is a partly mucous, partly albuminous secretion into which the spermatozoa pass, and a single

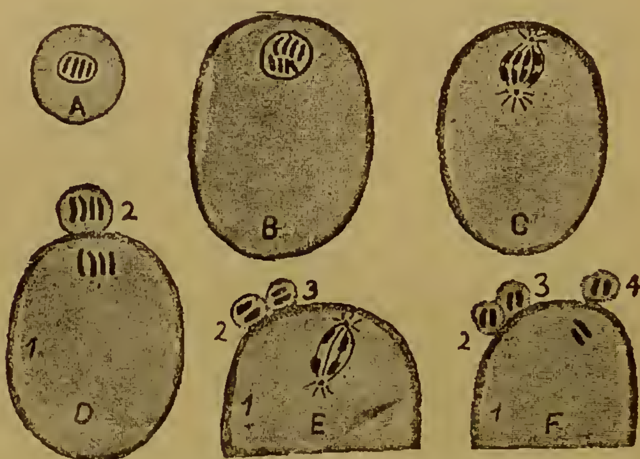

FIG. 65.—Diagram of Ovogenesis. **A.** Primitive ovum. **B.** Ripe ovum with eight chromosomes. **C.** and **D.** First or equal division. **2.** Polar body. **E.** Second reducing division of polar body and of egg. **F.** Ripe egg.

drop of semen contains many hundreds of them. The most common shape is tadpole like, but many other shapes exist in lower animals.

The ovary, like the testis, consists of a mass of cells which may give rise to female cells or ova. These are not, as in the testis, arranged in tubes, but in little masses or follicles, each follicle usually consisting of one cell which will become an ovum surrounded by many cells which form food-yolk for the ovum. The ovum, like the spermatozoon, has a definite number of chromosomes in the nucleus, in all probability the same number as are present in the sperm-mother-cell of the same species.

As in the case of the sperm-mother-cell the primitive ovum divides, but the division is confined to the nucleus. It takes place after division of the chromosomes, and the half-nucleus containing half the number of chromosomes (Fig. 65) is extruded from the cell and remains attached to it on the outside. In this condition it forms what is called a **polar body**. The remaining nucleus again divides without first doubling the number of chromosomes, and this half is extruded as a second polar body containing two chromosomes. There is thus left behind an egg-cell with the chromosomes reduced by the extrusion of two polar bodies to two in number and a centrosome. The polar bodies simply disappear. While this has been occurring the follicle cells have been pouring yolk granules into the ovum. This serves for the nourishment of the future embryo in its early stages of development. In some cases, as for instance in man, only an exceedingly small quantity of food-yolk is formed, and the cell remains small and invisible to the naked eye. In other cases, as in the dog-fish, a very large quantity of yolk is added, and the whole cell become bloated and is very large. The yellow yolk of a hen's egg, for instance, is the egg-cell expanded till its diameter is nearly an inch, by the addition of food-yolk.

The egg-cell in this ripe condition is discharged from the ovary and may escape from the body of the parent to be fertilised in the water, or it may remain within the mother in a special duct leading to the uterus or womb, when the animal possesses such an organ. In the dog-fish it remains in the oviduct until it has been fertilised: in the frog it is pressed out of the body by the male frog, and the spermatozoa come in contact with it in the water as it leaves the body. The essential part of fertilisation is the union of one spermatozoon with the ovum. It is usually the first spermatozoon that reaches the egg that penetrates it to effect this. In most cases any additional spermatozoa that reach the egg fail to penetrate it;

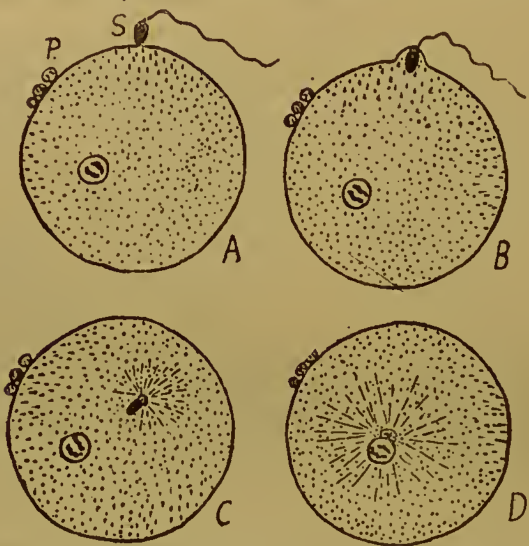

FIG. 66.—Diagram of Impregnation. **A.** Mature egg with approaching spermatozoon (and polar bodies still attached). **B.** The head and centrosome of the spermatozoon have entered the egg. **C.** The two draw together. **D.** Fertilized sperm-ovum with centrosome.

when they succeed a quite abnormal method of division results, and after a short time the egg-cell dies. Of the successful spermatozoon, only the head or nucleus, and the middle piece or centrosome, actually penetrate. The tail drops off and disappears. Radiating lines of protoplasm form round both the original nucleus of the ovum and the immigrant nucleus of the spermatozoon. The two gradually draw nearer and ultimately fuse. In most cases it appears that the centrosome of the ovum disappears, while the centrosome that came in with the spermatozoon persists and forms the centrosome of the fertilised egg-cell which is now ready to divide.

Thus we see that the new organism, in the case of the sexual reproduction of metazoa, is produced from the cell which results from the conjugation of an egg-cell and a sperm-cell. But as a matter of fact, the cell so formed derives its separate elements unequally from male and female. All the protoplasm of the cell-body is that of the female. The centrosome is that of the male. The nuclear matter consists of two chromosomes from the female and two chromosomes from the male. As a matter of common observation, we know that children or animals inherit as much from their fathers as from their mothers. It is to be inferred from this that if the inherited characters are conveyed by the male and female cells, and we know of no other way in which they could be conveyed, they are conveyed by some part of the sexual cells to which both parents contribute equally. It is the chromosomes of the nucleus which are equally contributed by both parents, in the figures each supplying two. Accordingly, *it is generally believed that the chromatin of the nucleus is the bearer of inherited characters.*

The centrosome is almost certainly an organ of division, and, as we have seen, it may be derived simply from the male, although in some cases the centrosome of the ovum also persists. The protoplasm of the body of the egg alone is present in the fertilised cell. In one case it has been shown by actual experiment that it does not act as the bearer of maternal characters. A German investigator was able to remove the nucleus from the egg-cells of one species, which may be called species A. Then he poured over the eggs spermatozoa from another species, which we may call B. He found that the eggs developed into young embryoes of the species B. As there was present only male nuclear matter, only the characters of the species to which the male belonged were transmitted.

We see, then, that the nucleus of cells has one important and special function. It is the part of the cell which, when the cell conjugates with another, or divides, is the bearer of the characters of the cell.

In addition to what has been mentioned, an important set of secondary structures are frequently developed round the egg. These serve as shells or membranes which protect the young embryo during the early stages of its growth. They are formed in very different ways, and there may be several of them present in a single case. The simplest is a cell-wall formed from the protoplasm of the egg itself. This is generally a very thin and delicate structure, but round about it other protective membranes may be formed, especially when, from the presence of much food-yolk, the egg is large and bulky. The follicle-cells which surrounded the ovum while it was in the ovary may form a stout membrane or shell which is often horny. Then, when the egg is travelling down the oviduct towards the exterior, the walls of the oviduct may form round it a gelatinous or albuminous layer. Lastly, sometimes from special glands in the lower part of the oviduct or in the uterus, an external shell may be added. Thus the egg of a fowl is surrounded by a series of membranes of this kind. In the ovary it arises as a small cell of microscopic size. Into this yolk is poured from the follicle cells, and round it is formed a delicate cell-wall by its own protoplasm. This, however, disappears after a very short time, and when the egg leaves the ovary it is surrounded by a special membrane formed by secretion from the follicle-cells, and known as the **vitelline membrane.** When it passes into the upper portion of the oviduct, secreting cells pour round it the white-of-egg, or albuminous layer. In the middle region of the oviduct the outer part of the white-of-egg becomes hardened into the fibrous shell-membranes, and finally in the lowest portion of all the calcareous shell is deposited by a special set of cells. Of course, in different animals the nature and method of deposition of the egg-membranes are different. Generally the entrance of the spermatozoon is effected before the formation of membranes, but in some cases a special aperture, the **micropyle,** is left in order to allow the entrance of the male cell. In such a case there is generally present only an inner, or vitelline membrane.

After fertilisation of the egg has been effected, cell-division, or, as it is called in the case of the egg-cell, **segmentation** occurs. The simple nature of this as a case of cell-division is disguised in those cases where much food-yolk is present. In such the nucleus divides, but the division does not extend completely through the large cell-body bloated as it is with inert food-yolk. Thus, in the case of the dog-fish, or fowl, the division of the nucleus is followed only by a partial division of the body of the cell, this attempt at division being represented by a furrow or line of cleavage, extending only a little distance into the surface of the yolk mass, As the presence of yolk complicates the method in which the subsequent stages of development take place, we shall describe the method of segmentation and development that occurs in cases where there is only a very small amount of yolk present in the egg. As all the divisions take place by the process of karyokinesis, which has already been described, no reference will be made to the internal occurrences during the repeated divisions by which the form of the animal is built up.

A fertilised egg-cell that contains little food-yolk divides first of all completely into two cells. Then each of these divide, forming four cells, each of these again forming eight, and each of the eight forming sixteen. The cells, or segmentation spheres, as they are called, assume a spherical form after each division and, as they adhere closely to each other, the whole embryo, after the four-cell stage, is a round, solid mass of cells with only the little interspaces between the cells that are the necessary result of the rounded form of the individual cells. Sometimes there is more of the food-yolk present in some of the cells than in the others. When this occurs it begins to be specially noticeable at the eight-cell stage. Four of these may be larger and contain most of the food material, the other four being smaller. The smaller cells are said to form the animal pole, and from them the ectoderm of the animal is formed, while

FIG. 67.—Four Stages in Cleavage; resulting in the Morula.

the larger, food-containing cells lie at what is called the **vegetative pole**, and give rise to the endoderm. On the other hand, no difference between the individual cells may be visible up to the sixteen-cell stage. Moreover, experiments show that there may be in some cases, at any rate, no difference between the characters and nature of the first sixteen cells. It has been found possible, by shaking embryoes of the two-, four-, eight-, and sixteen-cell stages completely to separate the cells from each other, and it has resulted that each of the separated cells, by division on its own account, formed an embryo by itself, the only difference being that these embryoes were proportionately smaller.

FIG. 68.—Section through Blastosphere.

The sixteen-cell stage from its appearance is called the **morula** or mulberry stage, and may be compared to a colonial protozoon. Its cells multiply rapidly by repeated division, and give rise to a single layered hollow sphere, the **blastosphere**, a section through which is represented in Fig. 68. In this stage, whether or no a distinction between the cells at the animal pole and the larger cells of the vegetative pole has previously appeared, such poles become obvious. The blastosphere, then, is a hollow sphere of cells arranged in a layer, one cell thick, with larger cells towards the lower or vegetative pole, and smaller cells towards the animal pole. The central cavity is termed the **segmentation cavity**. The next stage consists in the assumption of the

cœlenterate or **two-layered** type. This takes place by the larger cells moving inwards to form the inner layer. The simplest method by which this occurs in the embryoes of the vertebrate group is by the **invagination**, or infolding of the cells of the vegetative pole without any break in their continuity, as when a hollow indiarubber ball, pricked so that the air has escaped, shows a dimple that may be pushed in by the finger until the ball is turned into a two-layered cup. The embryo has now reached the cœlenterate type and is what is called a **gastrula** (Fig. 69). The central cavity is the **enteron**, the mouth of the gastrula is what is called the **blastopore**. The layers, in the embryonic condition, are given names which distinguish them from the similar layers of adult animals. The outer layer which corresponds to the ectoderm of hydra is called the **epiblast**. The inner layer corresponding to the endoderm of hydra is called the **hypoblast**. These two are the primitive germinal layers. The third layer which was spoken of as the mesoderm, and which is characteristic of the cœlomates, is termed the mesoblast, and, unlike the epiblast and hypoblast, is not a primary layer arising directly from the blastosphere. It is derived in different ways from the two primary layers, and consists of sets of cells of different nature.

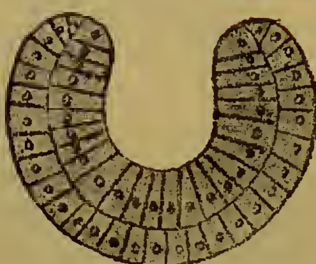

FIG. 69.—Section through Invaginate Gastrula.

The subsequent development of the gastrula into the cœlomate type becomes more and more complicated, and one has to notice several processes separately which are going on simultaneously in the actual development. Moreover, the general assumption of the cœlomate type is accompanied by the appearance of structures which are different in different groups of the cœlomates. It is therefore necessary to follow one of the types of cœlomate structure. That chosen here is the vertebrate or chordate type.

We shall have to deal separately with the great changes that take place in the embryo.

FIG. 70.—Surface view of Embryo with Blastopore (**B**) and neural fold (**NF**) surrounding it.

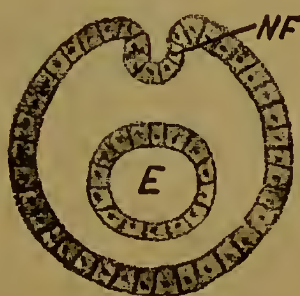

FIG. 71.—Cross Section through stage of Fig. 70. **E.** Enteron surrounded by hypoblast cells. **NF.** Neural fold.

First of all the gastrula becomes elongated and the blastopore lies at the posterior end. The opening becomes very much smaller on account of gradual growth round its edges. This growth is, however, not quite regular, but is more rapid at the sides and at the edge corresponding to the future ventral surface of the animal. Thus it happens that the blastopore gets pulled out into a long slit-like aperture, which extends a small distance over the dorsal surface of the embryo and terminates at the posterior end of the embryo.

Meantime a longitudinal furrow or groove appears along the dorsal surface of the epiblast from the anterior edge of the blastopore towards the anterior end. This groove becomes deeper and deeper, and finally its edges meet over the open groove and thus transform the groove into a canal. This tube, arising from the epiblast along the dorsal line, forms the dorsal nervous

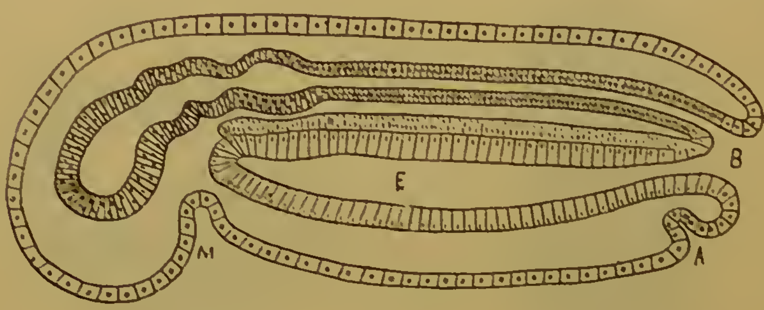

FIG. 72.—Longitudinal vertical section through a later stage. B. Blastopore leading into dorsally the nerve-tube, which in front is expanded into the three primitive vesicles of the brain: the blastopore lower down leads into E, the enteron, along the dorsal wall of which an expansion is forming the notochord. M. Invagination of epiblast to form the mouth; A. to form the anus.

system of vertebrates. The tube sinks down and the epiblast closes over it. At the anterior end it becomes enlarged to form three primary vesicles of the brain. Its posterior part forms the spinal cord, and the cavity of the tube becomes the cavity of the brain in front and the central canal of the spinal cord behind. The primary vesicles alter as described on page 213. At first this canal opens into the blastopore behind, but the lips of the elongated blastopore close over and meet just as the edges of the nerve furrow grew together to form a tube. In this way the spinal canal passes round the posterior end of the embryo under the closed lips of the blastopore and opens into the enteron or primitive gut. This connection is called the **neurenteric** canal, because it passes from the neural canal to the enteron (Fig. 72). Shortly afterwards a small pit appears in the

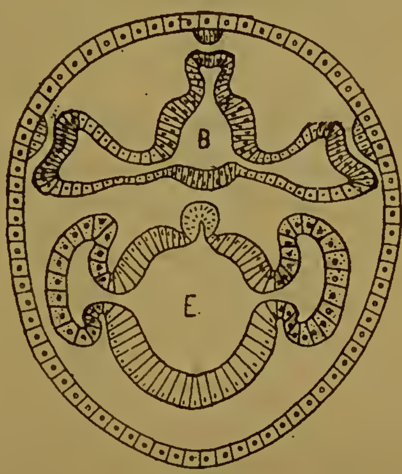

FIG. 73.—Transverse section through stage later than Fig. 72, taken through the thalamencephalon. **B.** Cavity of the ventricle with a dorsal prolongation forming the pineal, and lateral prolongations forming the lateral eyes. Opposite these a thickening in the epiblast is the rudiment of the lens. **E.** The enteron surrounded by hypoblast cells, with a dorsal fold—the notochord, and lateral folds—the enterocœles.

epiblast just below the closed edge of the blastopore. This epiblastic pit grows deeper until it breaks through into the posterior end of the enteron. This new opening forms the **anus** of the animal, and when it appears it destroys the neurenteric canal, and thus the nervous tube becomes closed at the posterior end. At the anterior end of the body of the embryo on the ventral surface an epiblastic pit like that which formed the anus appears. This grows deeper, and breaks through into the anterior blind end of the enteron and forms the mouth of the animal. At each side of the anterior end of the body, behind the mouth, four or five elongate epiblastic pits appear. These grow in towards the hypoblastic walls of the enteron, and opposite each epiblastic pit a hollow hypoblastic bud grows out. The pits from the outside grow into the buds which come from the inside, and in this way four or five slit-like apertures from the exterior open into the anterior sides of the enteron. These form the **gill-slits** (Fig. 74).

While these important changes have been going on in the epiblast an equally important set of changes results in the formation of the **cœlome.** The primitive method of this among the vertebrates consists of the formation of a number of pairs of outgrowths from the enteron. These outgrowths or **enterocœles** are hollow buds from the hypoblast (Fig. 73), which arise opposite each other all along the length of the gut beginning from the anterior end. At the same time all along the dorsal line of the enteron opposite and below the epiblastic nerve tube there is formed a fold of the hypoblastic wall of the gut. The lateral buds or enterocœles and the dorsal fold separate from the gut at the same time. The walls of the dorsal fold separate from the gut, grow together, and transform the fold into a long solid rod of cells lying between the nerve-tube and the gut. This rod of cells is the notochord or chorda dorsalis, and is the predecessor of the vertebral column. The edges of the enterocœles meet each other, and the cavities thus become continuous along the sides of the gut. They also meet round the under surface of the gut. Thus there is formed a space, the **cœlome** of the future animal, folded round the gut and

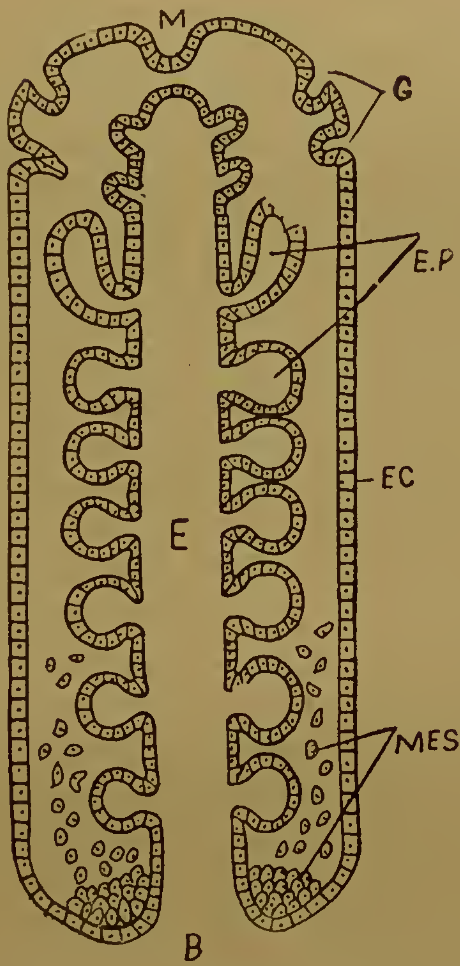

FIG. 74.—Horizontal longitudinal section through a simple Vertebrate Embryo in region of Enteron. **M.** Invagination of epiblast to form mouth. **G.** Invaginations of epiblast to form gill-slits. **B.** Blastopore. **E.** Enteron lined by hypoblast. The wall of the enteron in front has lateral diverticula which run towards the epiblastic gill invaginations. **EP.** Paired enterocœles, the cavities of which fuse to form the cœlome, and the walls of which form part of the mesoblast. **MES.** Mesenchyme cells migrating inwards from round walls of blastopore.

continuous under it, but not above it, as the notochord lies between the edges of its walls. A rough model of the arrangement of these structures will make their relations clearer. Suppose we represent the gut by a piece of drain-pipe. A solid cylindrical rod of wood like the piece of a mast may be fixed along the top of this to represent the notochord. Next let us take a flock mattress of the same length as the drain-pipe and place the drain-pipe with the rod of wood fixed along its upper surface on the middle of the mattress along its length. Then let the free parts of the mattress be bent round the drain-pipe until the two edges are in contact with each side of the rod of wood. The flock or stuffing of the mattress represents the hollow of the cœlome. The ticking of which the mattress is made represents the cellular walls of the cœlome. The upper surface of this is closely applied to the drain-pipe or gut where it is in contact with the notochord or rod of wood. The upper surface is continuous with the under, which, however, runs right round the pipe separated from the outer surface by the stuffing or cœlomic cavity, until at the other side of the notochord it again meets the upper edge. In the actual embryo, however, the outer and inner layers are fused together for a short distance on each side of the notochord. These fused longitudinal bands, lying on each side of the notochord, very early exhibit signs of segmentation, which is a striking character in the bodies of vertebrates. They break up into a row of what are called primitive segments, and from these are formed among other things all the transversely striped voluntary muscles of the body. The remaining part of the wall of the cœlome remains in the adult as the lining epithelium of the body cavity.

These structures formed from the walls of the enterocœlic pouches form a great part of the mesoblast or middle embryonic layer of vertebrates. But with it there come to be associated structures which have no direct connection with the enterocœle. First of all the sexual cells, those which give rise to the ovary and to the testis, in some cases are separated from the developing ovum before even the blastosphere stage, and therefore before the epiblast and hypoblast become distinct. In other cases they do not become visible as separate cells till later. In the vertebrates these primitive sexual cells, at whatever time they be actually separated from the other cells, become associated with the mesoblast, and appear as prominent patches of cells in the inner wall of the body cavity high up near the place where the outer and inner walls of the body cavity fuse together to form the primitive segments.

Next there is reason to believe that the nephridia, out of which the kidneys of vertebrates are formed, are partly at least epiblastic organs, but in vertebrates the first appearance of these as structures that can be identified is in the mesoblastic wall of the cœlome near the genital cells. So the beginning of these excretory organs is part of the mass of cells called the mesoblast.

Lastly, in some lower groups of cœlomates a set of wandering amœboid cells liberate themselves from both epiblast and hypoblast, and pass between the cœlome and the epiblast and hypoblast. These cells give rise to the blood corpuscles, to cœlomic corpuscles where, as in the earthworm, such exist, to the blood-vessels, and to the connective tissue and skeletal structures. In vertebrates these wandering cells, which have been called the **mesenchyme**, appear to be derived chiefly but not entirely from the inner layer of hypoblast, but they are detached chiefly from the walls of the blastopore. But they are distinguished by the fact that they come off not as layers or pouches of cells, but as separate migratory cells which are budded off in definite places.

It is clear, then, that the mesoblast or middle layer of vertebrates is not a simple structure like the hypoblast and epiblast, but is a condensation of a great many separate elements.

It will be convenient to put together in a tabular way the primitive organs of the embryo and the structures to which these give rise.

- Spermatozoon. + Ovum.
  - Fertilised Ovum.
    - Morula.
      - Blastosphere.
        - Epiblast.
          - Epidermis of Body and Lining of Mouth and Anus, with Hairs, Nails, and Lining of Skin Glands.
          - Nervous System.
          - Epithelium of Organs of Sense.
          - Lens of Eye.
        - Hypoblast.
          - Mesoblast.
            - Mesenchyme.
              - Connective Tissues and Skeletal Tissues.
              - Blood-vessels and Blood.
              - Lymphoid Organs.
              - Unstriped Muscles.
            - Wall of Cœlome.
              - Primitive Segments.
                - Voluntary Muscles.
              - Lateral Plates.
              - Epithelium of Body Cavity.
              - Sexual Cells.
              - Excretory Organs (Kidneys).
          - Notochord.
          - Lining Epithelium of Alimentary Canal and its Glands.

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